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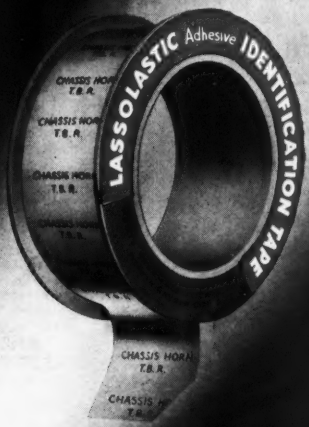

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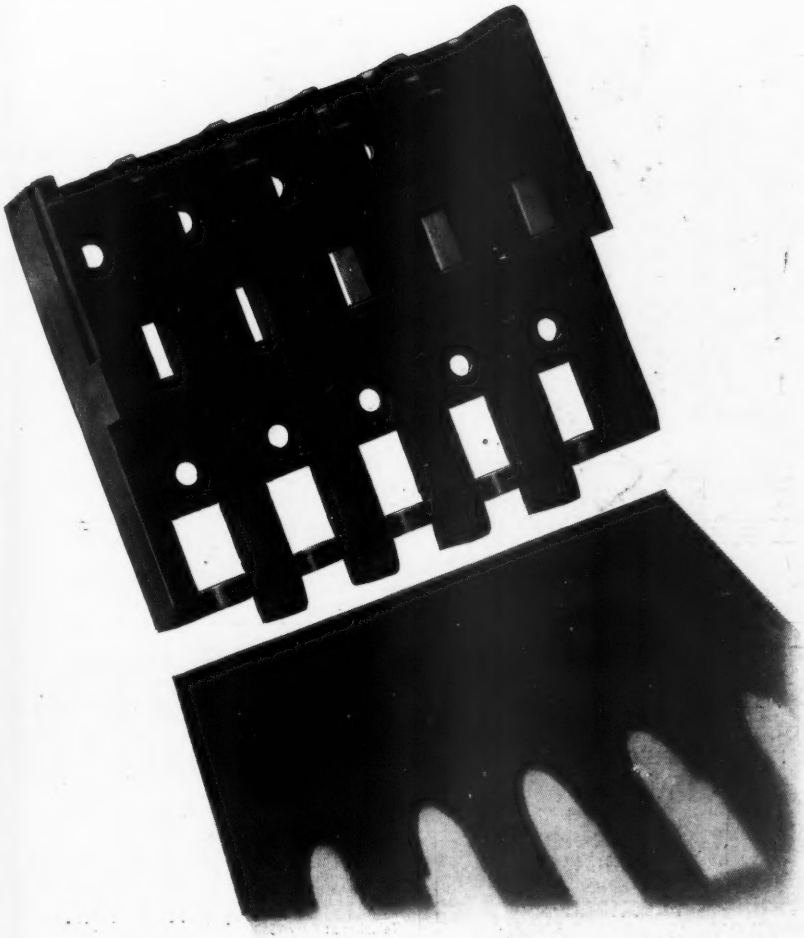

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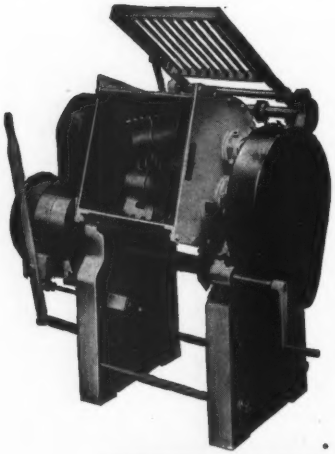

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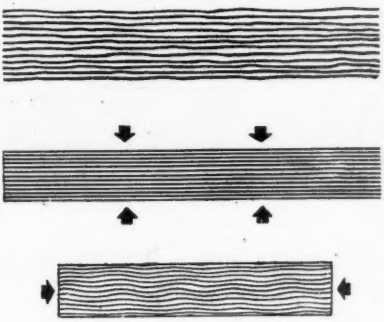

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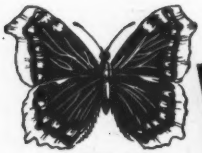

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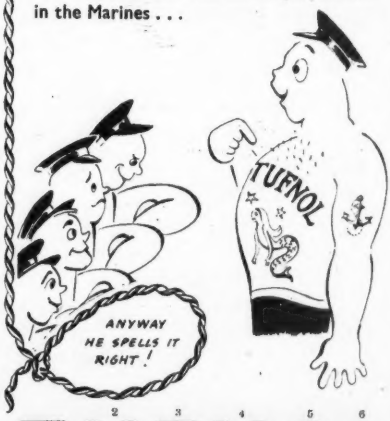

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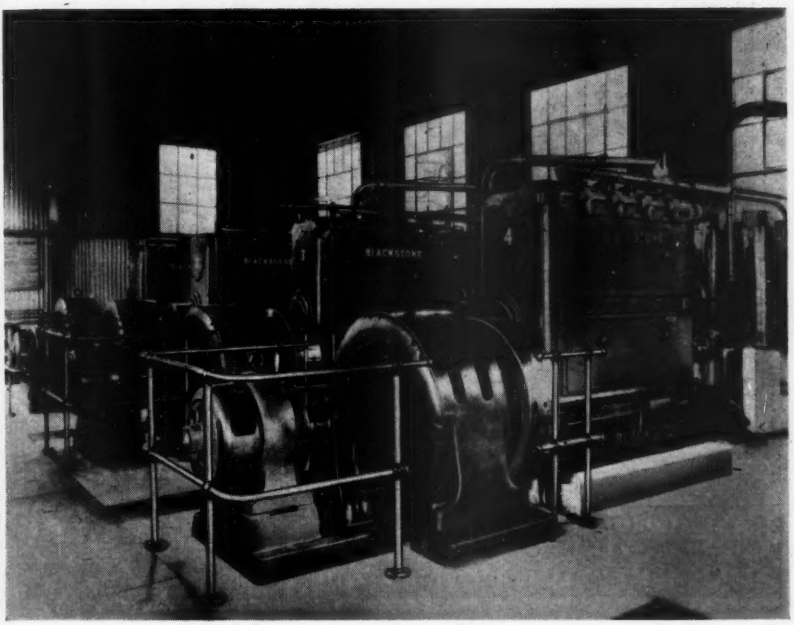

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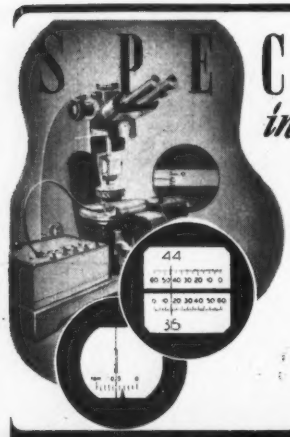

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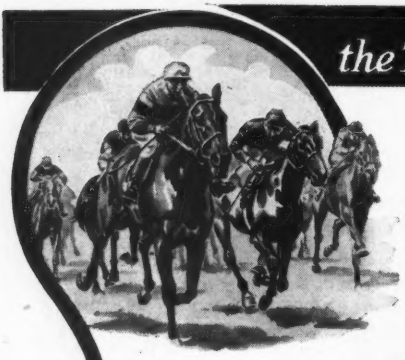

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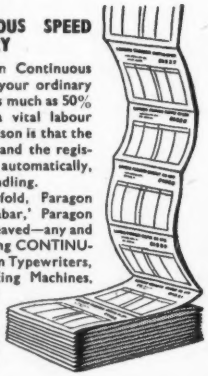

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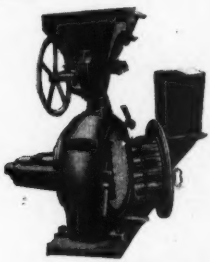

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Most forms of Bakelite Plastics are now playing an important part in equipping our fighting forces and are therefore not available to private users. The experience gained in these new fields will, however, prove invaluable to manufacturers in many industries when we can again turn our minds to peacetime problems.

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Vol. VII. No. 72 MAY, 1943

Plastics

Dealing with the Manufacture, Uses and Potentialities of Plastic Materials

Proprietors - - TEMPLE PRESS LIMITED
Managing Director - ROLAND E. DANGERFIELD

Editor - M. D. CURWEN, B.Sc., A.I.C.
Offices - Bowling Green Lane, London, E.C.1

CONTENTS

	Page
Editorials	186
Polyvinyl-acetate Adhesives, by E. E. Halls	189
New Plastic Cylinder for Servo Unit	194
World's Largest Rolling Mill	196
Scope of Plastics in Automobile Engineering, by G. Warburton Brown ..	201
World's Industry Employs Plastics	209
Ultracentrifuge with Plastic Rotor	212
Aircraft Parts of Impregnated Paper, by H. W. Perry	214
Joining Light Alloys with Adhesives	216
Production News	219
Resinoids and Other Plastics as Film Formers, by B. J. Brajnikoff	222

NOTICES

All instructions, matter and passed proofs for all kinds of advertisements must reach the Head Office of "PLASTICS" by the 24th of each month to ensure insertion in the following month's issue.

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Bowling Green Lane, London, E.C.1.
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More than ever is paper waste required for our war industries. Waste paper makes munitions in a hundred forms—from shell cases to aeroplane parts.

The fact that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

EDITORIALS

Advertising Plastics

A SHORT time ago we described Mr. Kenneth Chance's speech to the shareholders of his company, British Industrial Plastics, Ltd., as being unique in the history of industry—in the broad-mindedness of its general tenor and in its definition of the relationship between employer and employee. It seemed to us worthy to record that this and other trends showed that the plastics industry, in spite of its so-called youth or perhaps because of it, was giving a lead to the rest of the world in a new play of industrial manners.

The lead has now been emphasized and improved upon still further in a most exhilarating manner. This has been brought about with the publication by the same concern of a new type of advertising in the national Press. One of these runs as follows:—

What are Plastics?

One might as well ask "What are metals?"—for Plastics are becoming as numerous and varied as the older raw materials. All are different, behave differently and have their own particular usefulness to Industry.

To name a few members of the Plastic family there are Celluloid, "Erinoid," "Bakelite," "Beetle," "Perspex," Nylon, "Rhodoid," "Scarab," Melamine, Vinyl, Styrene. All are different, and each has its own peculiar properties and uses. We do not make all the plastics mentioned above; indeed, many of them bear the trade names of other manufacturers.

If you think you could use Plastics as raw materials for your industry our advice is freely given. If one of our Plastics is suitable for your use we shall recommend it. If not, we shall quickly put you in touch with another manufacturer able to supply a Plastic which is more suited to your particular job. It is of more interest to us that you use the right Plastic than that you should use one of ours at all costs. A Plastic wrongly chosen can result in a bad product which would only bring discredit to an industry to which we are proud to belong.

We do not know what our readers think of it, but we assure them it has stirred certain pools of silence and stagnation that have been long forgotten and ignored because of the adjacent glittering stream of Fleet Street publicity. To say the least of it, we have a new standard, and since we do not wish to delve into realms of morality, we can call it a new standard of business.

For the first time in the chequered history of industrial publicity has one manufacturer mentioned by name and commented favourably on the products of a "rival" company or admitted, indeed stressed, that one's own products may not be suitable for a particular job.

This is certainly good business. The method is probably applicable only to the plastic industry, which produces so many different types of material, about which the general public is so completely befogged that a vast clearing-up must be undertaken before real progress can be made. What must also be behind the new advertising campaign is a realization that expansion of the industry will be so great as a result of clear thinking and clear talking that there will be ample business for all types.

We do not necessarily advocate collaboration of this type in all industries and we shall probably never see the advertisement "If a Johnnie Walker does not suit your palate—try a White Horse" decorating our street hoardings, but at least a none too healthy blood stream is being rejuvenated.

Extending Co-operation

SUCH collaboration naturally brings to mind the question of how far can co-operation with outside industries be brought about and, of course, how far it is desirable or worth while.

Many writers in the technical Press, especially those dealing with metals, rubber, wood and the older materials of construction, have warned their readers of the impact of plastics and have treated plastics clearly as a dangerous enemy against which they must "take up arms against a sea of troubles and by opposing, end them."

We do not really quarrel with this attitude, for it is the intention of our industry to oust those materials where plastics will serve better physically, chemically and economically. Conversely we must prepare for reverses, against the time when those substances we have replaced are so improved as to oust plastics in their turn. We must expect it with metal, with wood or glass. Industrial life looked upon as a whole may at present be regarded as a see-saw existence without any permanent balance.

While a static condition is probably highly undesirable, yet another type of balance must surely be possible, one in which a wise authority can choose the best of more than one world and unite them in the perfect design.

Cannot, for example, the plastic and metal worlds be brought into closer collaboration? We have already had pronouncements by authorities that plastics are not the panacea for all industrial ills—it would be dangerous not to admit the fact loudly. It may be that the plastic-metal design is the solution to many problems. To take a simple example, there have been efforts to manufacture doors and windows purely from plastics and purely from light metals. Without knowing exact details, we should imagine that neither would stand the price test. But it is conceivable that a combination of thin metal sheet plus plastics (perhaps in the expanded form) would not be costly and could stand competition with wood. If this were true, then the plastics industry would have to learn a considerable amount about metal and its behaviour and the metal industry would have to turn its attention to plastics.

In the midst of war we are on the threshold of peace when reconstruction begins, and it is time we clarified our minds to prepare for the enormous problems which we must face.

Britain's Future Industries

WE'D give a month's pay to be able to live another 25 years just in order to see what the world will make of the chances that are offered to it. The effects of Lease-Lend, the promise of the Atlantic Charter, post-war reconstruction and the modern advances of science present us with a vista that sometimes appears too good to be true. What is certain is that this country, in spite of strong reactionary forces, has, with Governmental advice, realized the importance of maintaining a scientific and technical army without which we cannot hope to keep our place in the world of the future.

Readers may remember that at a recent lunch given by the Institute of the Plastics Industry, the chief guest, Mr. Butler, President of the Board of Education, promised that much would be done to further technical education and training in the future.

This promise is now to be carried into effect, for the Government have announced their intention to encourage new British industries based on recent inventions, discoveries and new industrial processes brought into being during the war, some of which are still secret.

To help the rapid expansion of new industries, among them are mentioned the technique of radiolocation, which will revolutionize television and radio, the whole range of plastics, new building methods and mass production generally, the men in the Forces will be given technical training at the Government's expense. Furthermore, the Government scheme includes higher education and technical training for men and women in the Forces and others whose careers have been interrupted by the war.

We are at last seeing the beginning of a design for the production of leaders of every phase of the national life.

Substitute Materials

AT the beginning of the war we published a short article on substitute materials, laying special stress on the need to employ properly the word "substitute," which, in our opinion, did not necessarily signify an inferior material, although, of course, it could mean just that.

The whole subject is now dealt with in a much more complete form by the publication of "Substitute Materials in War and Peace" by the Royal Institute of International Affairs. It has been written by Cecil H. Desch, F.R.S., the eminent metallurgist, so that the work may, on the whole, be considered authoritative and complete. It is an important contribution in petto to our view of the economic progress that takes place in war-time.

In his introduction the author reminds us of the words Ersatz (substitute) and Ersatzstoff (substitute material) which were associated in the mind with inferior substitutes for food and clothing when they acquired a derogatory meaning and were often used contemptuously. When the Nazi government set up its Four Years' Plan very extensive substitution was proposed, these terms were avoided on the ground that the newer materials were not to be extemporized substitutes, but were to be produced deliberately and to justify their existence by their own merits, sometimes exceeding those of the materials replaced. German writers now usually speak of Neue Werkstoffe (new materials) or where the change has taken the form of lowering the proportion of imported constituents, as of nickel in steels, the modified forms are described as Sparstoffarm (low in constituents involving foreign exchange).

The experience of the 1914-1918 war had shown that satisfactory Ersatz could not be extemporized and that patient research in many fields was essential. We can see that the results of such researches is the cause of the confounding of the confident prophecies that one of the belligerents would be forced to cease fighting at some given date owing to exhaustion of some essential raw material. The facilities which modern industry gives for the production of substitutes are the wonder of the whole world.

While no industry can produce an element, whether one of the metals or non-metals, artificially, yet with coal, oil, wood, an agricultural industry and power, any country can produce rubber-like materials, petrol, fertilizers, certain foods, plastics and fibres.

The main subjects dealt with in detail are synthetic substitutes for petroleum, substitutes for rubber, plastics, other organic materials and rubber. Each is dealt with in detail, and under petroleum the author discusses not only the production of petrol by the Bergius hydrogenation process, but also the Fischer Tropsch method of gasified coal to carbon monoxide and hydrogen and then causing these to react with the production of special fuels and lubricating oils, the use of benzole, alcohol (much of the French wine production was converted to alcohol by the Germans), town's gas, methane from sewage farms, producer gas, peat, and wood.

Rubber is also dealt with adequately by a résumé of synthetic rubber production in the U.S.A., Russia and Germany, and of the cultivation of many plants other than those normally grown for rubber.

Of plastics, Dr. Desch has many interesting and encouraging things to say. After describing their character and uses, he declares that the plastics industry is the most important of those concerned with new uses of raw materials, and would have reached its present position without the stimulus of war, but it has had the effect of relieving the war shortage of certain metals, including tin and aluminium, by providing satisfactory substitutes. It is, however, an example of the difficult problems associated with substitution that it is now reported from the United States that synthetic resins, having been so widely adopted as a means

(Continued on page 208)

Polyvinyl-acetate Adhesives

Some additional notes on these widely employed adhesives, which have already been discussed in the December, 1942, issue of "Plastics"

By E. E. HALLS

CEMENTS and adhesives having polyvinyl acetate as base, and supplied in solid or liquid form, have been in use in America for a long time, and are well recognized under the trade names of Gelvas or Alvas, and under the general description of vinyl adhesives. These materials have earned their position in industry by their merits for securing not only porous or absorbent surfaces together, but also for cementing non-porous materials, both metallic and non-metallic. Strength of joint obtained is an outstanding characteristic.

The polyvinyl acetates offer several features that render them ideal for the production of adhesive solutions. They are soluble in a wide variety of organic solvents, including esters such as ethyl acetate, ketones such as acetone, hydrocarbons, such as benzene and toluene, chlorinated hydrocarbons, and methylated spirit or methylated spirit containing up to 40 per cent. of water. This provides a range of vehicles from which selection can be made to suit drying time, to meet non-inflammability requirements, or to yield varying degrees of "bite" when plastic materials such as cellulose acetate, methyl methacrylate and the like are in question. The polyvinyl acetates themselves can be produced over a range of molecular weights, these compounds in turn yielding solutions of a range of viscosities, the higher the molecular weight, the greater the viscosity of the solution. Again, they may be co-polymerized with polyvinyl chloride to give yet further modifications. Further, the polyvinyl acetates are compatible with many other synthetics, such as nitro-cellulose, cellulose acetate, and ethyl cellulose, as well as with many plasticizers, e.g., triethylene glycol hexoate, diphenyl, diphenyl methane, tributyrin, and isoamyl phthalate. An infinite field of possibilities in consequence exists for modifying the flexibility, hardness, water resistance or other properties of the bond.

Types of Adhesive

Besides the solution and powder forms of these adhesives, mention should be made of coated papers. Thus forms equivalent to the thin shellac-coated papers known as photomounter's tissue, have been available in this country. They find application for jointing non-porous materials under pressure and heat. Hard brass, 1-64 in. thick, has been secured to itself by this means, practical details being to bring the assembly to 130-150 degrees C., apply relatively light pressure (e.g., 300 to 1,000 lb./sq. in.), and cool off. Mica to metal is another combination difficult to secure that has been successfully achieved with this polyvinyl-acetate-coated paper. In this case, the parts were assembled under pressure and placed in an oven at 110 degrees C. for about 15 minutes. The resultant junction could not be disturbed without wrecking the mica. In fact, lamination of the latter proved to be the weak feature. Both rigid and flexible metal bases have been used. The rigid metal was steel, 1-32 in. and 1-16 in. thick, and the mica was 0.003-0.004 in. thick. The flexible metal was hard brass, 0.0035 in. thick, with the same mica. The components were circular, a range being concerned, from $\frac{3}{4}$ in. to $4\frac{1}{2}$ ins. dia. The arrangement of the assemblies are shown in Figs. 1 and 2. This application is in accord with the many American uses where metal, glass and porcelain have been the materials joined, and comparable with the use of

polyvinyl-acetate-base adhesives in the production of laminated glass.

It is to be noted that the water-resisting properties of many of these adhesives are good and that electrical qualities are high. Electric strength is of the order of 1,000 volts A.C. per mil of thickness. Qualities

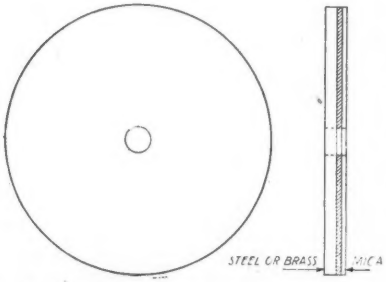


Fig. 1.—Sticking steel or brass to mica with P.V. acetate paper (shown shaded).

can be chosen that are non-corrosive, although none of them is seriously active in this sense. Apart from possible applications in the manufacture of laminated products (glass, wood, fabrics), the securing of fibrous materials to metal, and for general glueing and sealing purposes, these qualities open fields in the light electrical industries, with possibilities in valve basing, securing of ceramic insulators, fixing of synthetic resin compounds, etc.

Some reference was made to the polyvinyl-acetate adhesives in the article on "Adhesives and Cements," in the April, 1941, issue of "Plastics," as well as in the issues of June, 1942, p. 183, and December, 1942, p. 431. It is important to note that developments are continuing with the production of these adhesives in this country, and the following deals with tests on further products of this type. The tests were designed to be very general in nature rather than in relation to specific applications.

These further investigations were made on a number of polyvinyl-acetate adhesive solutions along similar lines to those previously carried out. Five samples were tested representing two types of adhesive in different concentrations. Compositional data appertaining to them are given in Table 1, which shows that the type A material was represented in three concentrations, low, medium and high, and the type B material in two concentrations, low and medium. The acid values of the solutions are given, these being determined in the following manner:—

About 5 grams of the adhesive was dissolved in 100 ml. of a 50/50 mixture of benzene and alcohol, and titrated hot with N/20 potassium hydroxide solution using phenol phthalein as indicator. It will be noted that for the first four samples the acidities are of the order of 1.0 and the materials are very good in this respect. The fifth sample shows a higher value of the order of 10.0, but no detriment from this showed up during the tests, e.g., no corrosion of brass. The material, therefore, in this respect is con-

Table 1.—Compositional Characteristics of Polyvinyl-acetate Solutions.

Type	A			B	
Sample	1	2	3	4	5
Composition, per cent.: Volatile spirit (3 hrs. at 110°C.)	89.2	74.4	63.0	90.0	81.0
Total solids	10.8	25.6	37.0	10.0	19.0
	100.0	100.0	100.0	100.0	100.0
Acid value: Mgms. KOH/gm. of base	1.2	0.8	0.6	0.9	9.0

Table 2.—Examination of Polyvinyl-acetate Adhesive Junctions after 21 days' Exposure at Laboratory Temperature.

Combination No.	Materials joined	Type A			Type B	
		Sample No. 1	2	3	4	5
1	Phenolic laminated to paper	Poor	Excellent	Excellent	Poor	Excellent
2	Phenolic laminated to phenolic laminated ..	Good	Excellent	Excellent	Poor	Excellent
3	Plywood to plywood ..	Poor	Very good	Excellent	Poor	Fairly good
4	Phenolic laminated to plywood	Poor	Fairly good	Very fair	Poor	Poor
5	Phenolic laminated to brass	Poor	Poor	Poor	Poor	Fairly good
6	Brass to plywood	Poor	Poor	Poor	Poor	Poor
7	Soft rubber to plywood ..	Poor	Fairly good	Fair	Poor	Poor
8	Bituminized cement asbestos board to bituminized cement asbestos board	Poor	Very good	Very good	Poor	Poor

sidered satisfactory and in fact the value may not represent an actual acidity so much as a saponification value of one of the solvents or plasticizers incorporated in it.

Adhesive quality of the materials was explored using the same range of combination of materials as previously employed, namely:—

(1) A high grade of phenolic laminated sheet to paper.

(2) Phenolic laminated sheet to phenolic laminated sheet.

(3) Plywood to plywood.

(4) Phenolic laminated sheet to plywood.

(5) Phenolic laminated sheet to brass.

(6) Brass to plywood.

(7) Soft rubber to plywood.

(8) Bituminized cement asbestos board to bituminized cement asbestos board.

Specimens were 1 in. wide and were joined together to give 1 in. overlap. The adhesive was applied by brush to both mating surfaces, which were then pressed together and held under gentle pressure in a vice for one hour. They were then allowed time to enable them to fully dry out by exposure for three days to ordinary laboratory temperature before testing.

Before examining all the adhesives with the full range of combinations of materials under all the exposure tests, the full range of materials were cemented with all the samples and exposed to laboratory temperatures for three weeks and then examined. The more inferior samples were not further considered and the tests applied only to the more promising ones. These tests comprised the following separate sets of conditions:—

(a) Exposure for 21 days to fluctuating warmth and moisture in a cabinet to give the following approximate conditions:—

Day temperature 55-60 degrees C. and 65-75 per cent. humidity, cooling off at night to atmospheric temperature with rise in humidity to 100 per cent. and condensation of moisture on all specimens.

(b) Complete immersion in water at laboratory temperatures.

(c) Exposure in a solid carbon dioxide chamber to a temperature of minus 50 degrees C., holding for two days with temperature between minus 50 and minus 40 degrees C.

For easy comparison of the properties of the various adhesives and the extent of their deterioration or improvement under the test conditions, all results have been concisely tabulated with a separate table for each set of conditions, namely Tables 2, 3, 4 and 5. In these tables the following expressions have been used:—

A. Excellent, signifying that the joints could not be separated, or only separated with great difficulty.

B. Very good, signifying difficulty in separation, but slightly easier than A.

C. Good, withstanding reasonable pull in tension, but still separating.

D. Fairly good, the joint being tenacious, but could be separated.

E. Very fair, could be separated.

F. Fair, separation still easier than E.

G. Poor, could be separated very easily.

The specimens that were poor after three weeks' exposure at ordinary temperatures were not proceeded with on the other tests.

A broad review of the tabulated data shows that the lower concentrations of both types of cement are poor, while the higher concentrations, particularly type 2, are very good in most cases. Again, the general conclusion is that complete water immersion is detrimental, although there were one or two instances where the junction still remained sound, e.g., adhesive No. 3 for phenolic laminated to itself and

Table 3.—Examination of Polyvinyl-acetate Adhesive Junctions after 21 Days' Exposure to Hot and Cold Humidity Conditions.

Combination No.	Materials Joined	Type A			Type B	
		Sample No. 1	2	3	4	5
1	Phenolic laminated to paper	—	Excellent	Excellent	—	Excellent
2	Phenolic laminated to phenolic laminated	Poor, deteriorated	Very good, only slight deterioration	Excellent	—	Good, some deterioration
3	Plywood to plywood	—	Good, only slight deterioration	Very good, only slight deterioration	—	—
4	Phenolic laminated to plywood	—	Good	Good, improved	—	—
5	Phenolic laminated to brass	—	—	—	—	—
6	Brass to plywood	—	—	—	—	—
7	Soft rubber to plywood	—	Fairly good	Very good, improved	—	—
8	Bituminized cement asbestos board to bituminized cement asbestos board	—	Good, only slight deterioration	Poor, deteriorated	—	—

Table 4.—Examination of Polyvinyl-acetate Adhesive Junctions after 21 Days' Immersion in Water at 20°C.

Combination No.	Materials joined	Type A			Type B	
		Sample No. 1	2	3	4	5
1	Phenolic laminated to paper	—	Poor, deteriorated	Poor, deteriorated	—	Good, slight deterioration
2	Phenolic laminated to phenolic laminated	Poor, deteriorated	Poor, deteriorated	Good, some deterioration	—	Poor, deteriorated
3	Plywood to plywood	—	Poor, deteriorated	Poor, deteriorated	—	—
4	Phenolic laminated to plywood	—	Poor, deteriorated	Poor, deteriorated	—	—
5	Phenolic laminated to brass	—	—	—	—	—
6	Brass to plywood	—	—	—	—	—
7	Soft rubber to plywood	—	Poor, deteriorated	Very good, improved	—	—
8	Bituminized cement asbestos board to bituminized cement asbestos board	—	Poor, deteriorated	Poor, deteriorated	—	—

Table 5.—Examination of Polyvinyl-acetate Adhesive Junctions after 2 Days' Exposure to cold at −40/−50°C.

Combination No.	Materials joined	Type A			Type B	
		Sample No. 1	2	3	4	5
1	Phenolic laminated to paper	—	Excellent	Excellent	—	Excellent
2	Phenolic laminated to phenolic laminated	Poor, deteriorated	Very good, only slight deterioration	Excellent	—	Good, some deterioration
3	Plywood to plywood	—	Excellent, improved	Excellent	—	—
4	Phenolic laminated to plywood	—	Poor, deteriorated	Poor, deteriorated	—	—
5	Phenolic laminated to brass	—	—	—	—	—
6	Brass to plywood	—	—	—	—	—
7	Soft rubber to plywood	—	Good, improved	Very good, improved	—	—
8	Bituminized cement asbestos board to bituminized cement asbestos board	—	Fairly good, slight deterioration	Good, only slight deterioration	—	—

for rubber to plywood. Exposure to cold in general produced no deterioration, a notable exception being the case of plywood to phenolic laminated.

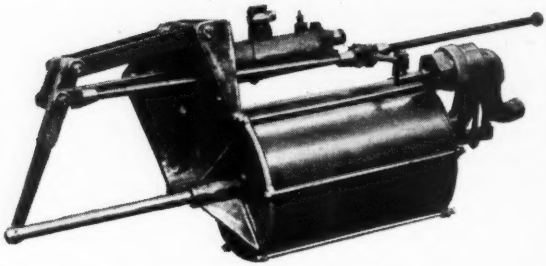
It is presumed, therefore, that the lower concentrations of adhesives are ruled out for any of the purposes considered, but the others warrant attention. Thus, judged only on the atmospheric temperature tests, samples No. 2 and 3 of type A proved unsuitable for securing metal to phenolic laminated or to wood, but promising in all other respects, and exceedingly good for phenolic laminated to itself or to paper, for plywood to plywood, or for the very difficultly cemented bituminized asbestos products. Likewise, sample No. 5, the concentrated type B material, proved excellent for paper to phenolic laminated and phenolic laminated to itself. Further, little or no deterioration occurred with these under the fluctuating humidity conditions tests, but it did under the water test. Sample No. 5 was the only one that would withstand the water-immersion conditions, when used for securing paper to phenolic laminated, and No. 3 when used for phenolic laminated to itself, or for rubber to wood.

It will thus be seen there are a number of applications where these materials are quite suited, but selection has to be made with care if very damp conditions are to be encountered. Further developments have yet to be made, and while general purposes may have been satisfied to a considerable degree, specific applications and the requirements of specific service conditions have to be met.

Commodity Control

Since most factories are working under control of manufacture or under control of the supply of commodities, the understanding of the Emergency Legislation that has been imposed is a very necessary part of managerial equipment. Butterworth and Co., Ltd., has just published "Commodity Control," by Freeman and Hignett (price 15s.). In about 300 pages are compressed the raison d'être of the many emergency orders and statutes that have been imposed upon us, how they are enforced, the meaning of concentration of production, how and why control of employment and commodities are applied, price control, offences, penalties and proceedings, etc. Appendices include a complete schedule of Orders and Regulations, lists of Price Regulation Committees, addresses of Licensing Offices and of official departments and Government offices by whom control is applied. It would seem that no part of emergency legislation imposing control over some 160 types of material has been overlooked.

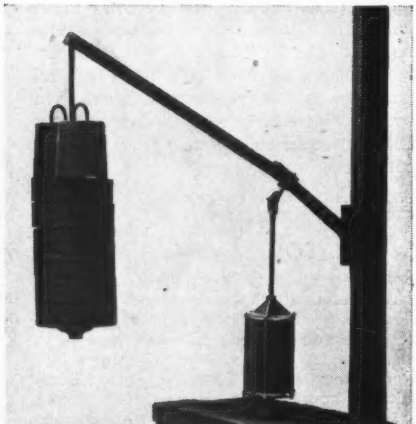
New Plastic Cylinder for Servo Unit



An 8-in. plastic cylinder assembly with 1.75-in. Lockheed master cylinder.

Practical Tests have Demonstrated that a Laminated-phenolic-resin Cylinder may Successfully Replace Rubber Bellows in Heavy-duty Servo Units

SOMEWHAT unfortunately, the exigencies of war have called for servo braking systems with a force in excess of 230 lb. at a time when rubber supplies have become very short, and before synthetics are available in sufficient quantity to meet the probable demand in this field.



A 6½-in.-bore plastic cylinder maintaining under pressure a dead load of 16 cwt.

The mechanical properties of the rubber mix, used for bellows on the servo of conventional design, are such that thick sections must necessarily be used. Thus, the bellows on one 230-lb. pull-type weigh 5½ lb., and it is to be presumed that models with greater loading capacity would consume proportionately still larger quantities of rubber.

It will be seen, then, that two difficulties had to be encountered. First, shortage of raw material; secondly, that of undesirable increase in the dead-weight of the component. To overcome these problems, Feeny and Johnson, Ltd., Ealing Road, Wembley, decided to carry out experiments on the replacement of the rubber bellows by plastic cylinders.

Preliminary trials proved highly successful and production is now under way. The material selected for the cylinder is a heavy-duty laminated phenolic, which, besides possessing the high strength to resist implosion or bursting, has also a high resistance to impact. This is clearly necessary, as, in service, the unit might be subjected to shock loading.

A somewhat spectacular view of a 10-in. plastic cylinder under ½-ton load.

During actual bench trials, two incidents occurred to demonstrate this last-named property. While a 6½-in. cylinder was being tested to 16 cwt. lift under pressure, and while the 10-in. cylinder was lifting (vacuum) a deadweight of ½ ton, the supporting chain tackle broke after peak load had been maintained for some few minutes. The cylinder units were shot with considerable violence on to a stone floor, but subsequent examination and retest showed that no cracking or other damage had occurred.

There are being manufactured, at the moment, cylinders of 6½-in., 8-in. and 10-in. bores. These give under vacuum pulls of approximately 330, 500 and 750 lb. respectively. The 6½-in. cylinder is also in production as a pressure unit.

It will be appreciated that, under operating conditions, the sliding properties of the bore are of importance. In no circumstances must this wear or develop roughness, occurrences which would, in either case, result in loss in efficiency and rapid destruction of the cup piston.

In practice, as has been demonstrated before, the phenolic resins provide an extremely hard, wear-resistant, smooth-running surface; they are indeed, as is well known, used for bearings.

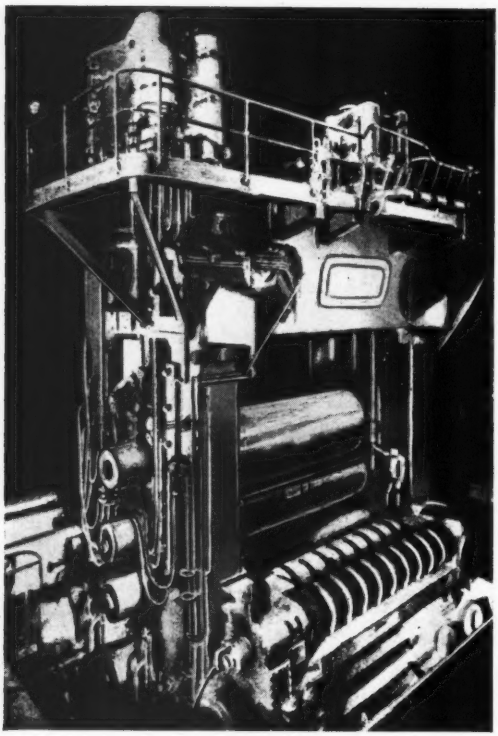
Perhaps the most striking advantage of the replacement of rubber by plastics is the great reduction in weight which is achieved. Thus, as already noted, a 230-lb. pull-type rubber bellows weighs 5½ lb.; the 330-lb. pull 6½-in. plastic cylinder weighs 1 lb. 1 oz.; the 8-in. cylinder 1 lb. 8 oz., and the 10-in. cylinder 2 lb. 8 oz. The pulling capacity of this last is more than three times that of the 5½-lb. rubber bellows, the weight of the unit being less than half.

As to the life in service of such a resin-impregnated cylinder, there is no doubt that from the point of view of oil and heat resistance it compares very favourably with the rubber type of bellows.

U.S. Synthetic Rubber

Mr. Robert Patterson, U.S. Under-Secretary for War, has stated that emphasis on the synthetic rubber programme had crippled production of high octane aviation spirit. This statement has been challenged by Mr. William Jeffers, the director of the synthetic rubber programme. The latter has issued the following:—

"The statement attributed to the Under-Secretary for War, and alleged to have been concurred in by the Secretary of the Interior, is so serious, and so seriously affects the war effort and the American people, and might contribute so materially to the comfort of the enemy, that it calls for an immediate investigation to bring out the true facts."



World's Largest Rolling Mill

Bearings for a new giant four-high plate mill are exclusively in plastics. Service tests have given admirable results

Fig. 1.—View of four-high plate mill after assembly in shop. The dimensions of this equipment may be judged from the figure of the operative to be seen at the right of the rolls.

PLASTIC bearings, correctly constructed and used, and designed according to the special working conditions to be encountered in rolling-mill practice, have given the greatest satisfaction in service. For this reason, it seems likely that in the future the ordinary non-ferrous metal bearings previously used will be entirely displaced by plastics. It is not surprising, therefore, that, in the new Demag 5.2 dia. four-high plate mill, plastic bearings have been incorporated as a standard and permanent feature.

Construction of the Mill

The rolls of the mill are in a low-alloy steel of forging quality. Working rolls are 1,100 mm. in dia. and backing rolls 1,600 mm. in dia., roll lengths being 5,200 mm. and 5,300 mm. respectively. Motive power is supplied by a five-cylinder reversing steam engine of 30,000 h.p.

An electric tilter is provided on which may be turned plates up to 165 tons in weight, 7.8 metres in length, 5.2 metres wide and 0.6 metre thick.

The complete mill is shown in Fig. 1. Plastic bearings are used in the assembly as follow:—

(1) For upper and lower backing rolls (1,050 mm. dia. roll neck).

(2) Working-roll bearings (770 mm. dia. roll neck).

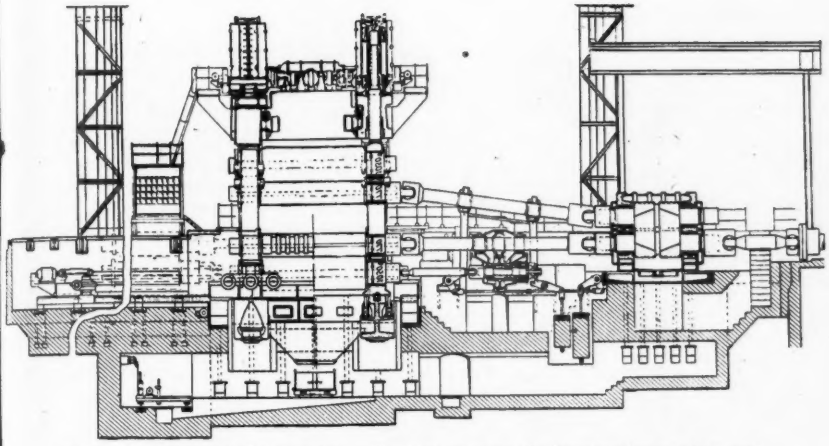


Fig. 2.—Front view of the complete mill. Not only are the bearings for working and backing rolls of plastics, but skids on the roll-changing gear are also of plastics construction.

(3) Bearings for countershaft in tilter (four bearings of 500 mm. dia., eight bearings of 300 mm. dia., and two bearings of 250 mm. dia.).

(4) As slides in the roll changing equipment.

(5) Bearings for worm wheels in screwdown.

(6) Guide bushes, sliding plates, etc., for minor purposes.

In the description which follows special attention will be paid to items 1 to 4. These are referred to also in Figs. 2 and 3.

Backing-roll Bearings

It has been shown that, in breaking down slabs between 15-165 tons in weight, the forces generated may safely

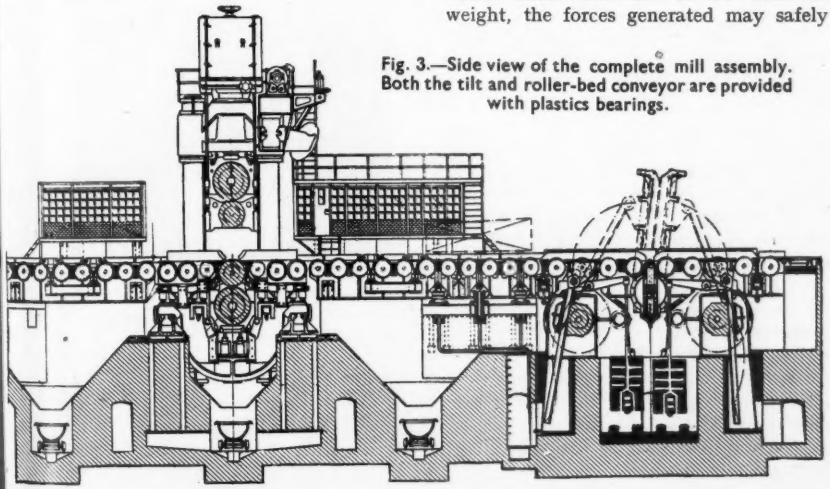


Fig. 3.—Side view of the complete mill assembly. Both the tilt and roller-bed conveyor are provided with plastics bearings.

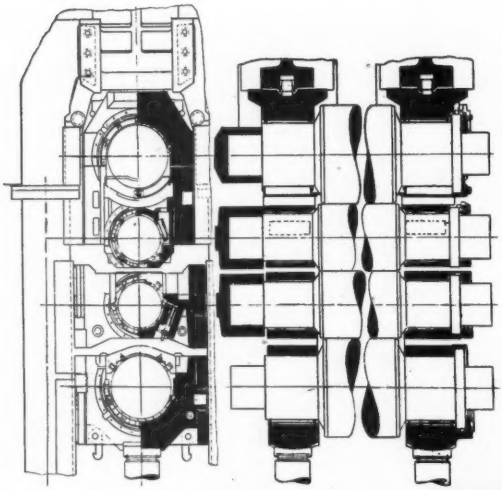
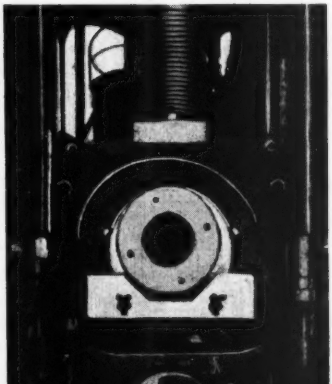


Fig. 4 (left).—Undimensioned working sketch showing front and side views of the bearing systems for the working and backing rolls. The bearings themselves are in a cotton laminate, shoulders for the bearings being in a cellulose-wool laminate.

Fig. 5 (below).—Close-up, end-on view of bearings for the upper backing roll and upper working roll. This view is taken from the inside of the frame looking out towards the wobbler end.



be taken up by plastic bearings and transmitted to the rollstand. The upper backing roll is not driven, whilst the lower backing roll is provided with a friction drive in order that it may rotate even when the mill is idling.

They are bored for the sake of lightness and are constructed in a 40-ton steel. The necks are 1,050 mm. dia. and 900 mm. long. The plastic bearings are built directly into the housing, and, on the inner side of the stand, are constructed as loose bearings, whilst on the outer side of the stand they are fixed. The houses themselves are so constructed that they can adjust themselves to take up by deflection in the roll neck in order that any edge pressure on the bearings may be avoided.

The bearings proper are in a cotton laminate, according to D.I.N. 7,703, whilst collars and flanges are in a cellulose-wool laminate.

The bearings, which take rolling pressures estimated at 3,000 tons per bearing and, in addition, absorb stresses occasioned by the entry of slabs between the rolls, are in the form of 120-degree segments (Fig. 4). The individual segments (amounting, in all, to seven per bearing) are mounted tightly between collars in the housing. Individual segments are preloaded by wedges and screws. In this way working life is prolonged and resistance to wear increased.

The bearings are lubricated with a suitable grease under high pressure and amply cooled by means of water. Lubricant is forced by an electric pump through tubes, flexible Buna connections,

and distributors over the whole length of the roll neck. Jets supply cooling water at high pressure in order to dissipate frictional heat and that absorbed by radiation from the material being rolled.

The suspended bearing has to take the load of the upper backing roll amounting to some 98 tons. This is also built up of separate plastic units to give a segment of about 60 degrees. Two bearings are provided in each suspended housing, a wide gap being placed between them. This is maintained full of cooling water (about 50 tons), together with pressure from the upper backing roll, also 50 tons, and, finally, any forces parallel to the direction of rolling which may arise during operation of the mill, and which, in unfavourable circumstances, may amount to as much as 10 per cent. of the total roll pressure (usually, however, these forces amount to a considerably smaller figure than this, but are extremely difficult to calculate).

The bearings of the working rolls are relieved entirely of the normal load occa-

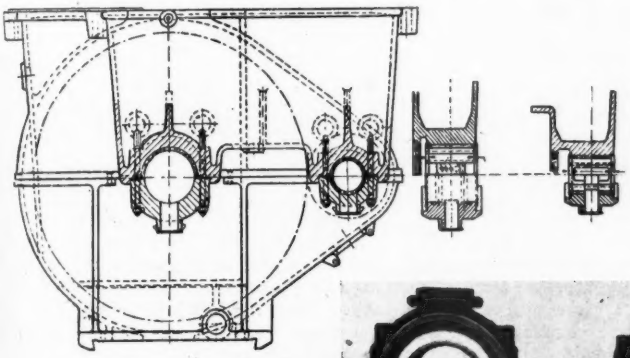


Fig. 6.—At the left. Sketch showing split bearing in cellulose-wool laminate in part of the plate-tilting mechanism.

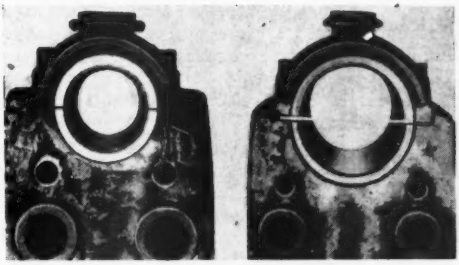


Fig. 7.—At the right. Close-up views of bearings forming part of the plate-tilting mechanism. These are illustrated diagrammatically in Fig. 6 above.

in order to increase the efficacy of heat dissipation.

In the case of the lower backing roll, a cooling box is provided for the same purpose, and this acts, simultaneously, as a shield to protect the lower backing roll neck against scale.

Working-roll Bearings

The working rolls are also bored and are forged from a 50-ton low-alloy steel. The roll necks are 770 mm. dia. and 850 mm. long. The bearings of the upper working roll must sustain a load consisting, first, of the weight of the roll itself sioned during actual rolling. These bearings must be fully adjustable in order that they may be brought into perfect axial alignment with the backing rolls even when the bearings themselves become worn. This is necessary in order that oblique loading may be avoided.

The bearings of the upper working roll have to sustain only the weight of their housings together with loads consequent upon forces parallel to the rolling direction arising during operation. In general, the bearings of the lower working roll are required to perform the same duties as those of the upper working roll.

E

Bearing construction to meet these requirements is shown in Fig. 4. Here, again, bearings are preloaded by means of wedges and screws in order to increase wear resistance. To take up forces parallel to the roll axes, thrust bearings are provided on the outer side of the roll stand. The collars are built up of a number of pieces and are chamfered on both sides in order to promote the formation of a film of lubricant. Gaps between the sections composing the collars are about 70 mm. wide and water and grease can enter here. In this way, overheating of the thrust bearings is prevented.

Fig. 5 gives an external view of the loose bearings of the upper working and backing rolls, and shows the housings and the liners.

Roll Changing Equipment

When changing rolls the lower backing roll, the two working rolls and their housings and other attachments are removed simultaneously. This entails the handling of a weight of some 300 tons. On practical grounds, wheeled mechanism was not adopted for the purpose, skids running on rails being employed instead. The rails are provided with racks with which the driven wheels of the changing mechanism mesh.

The sliding surfaces of the skids are furnished with a number of plates $\frac{3}{4}$ in. thick in a plastic to D.I.N. 7703. Specific loading of these surfaces amounts to about 700 lb./sq. in. and sliding speed about 19 ft./min.

The sliding surfaces lying inside the roll stand cannot be entirely protected against the effect of scale, water and condensation. The front end of the skids, therefore, are provided with movable, acutely chamfered cast-iron plates for the purpose of cleaning the rails. In addition, hand pumps are provided for greasing.

It should be noted, incidentally, that plastics of the type used tend to polish metal surfaces running in contact with them. In this respect they are superior to ordinary bearing metals. Moreover, under the operating conditions described and in the presence of a somewhat unsatisfactory lubricant, viz., water and grease, their sliding properties are superior to those of metal.

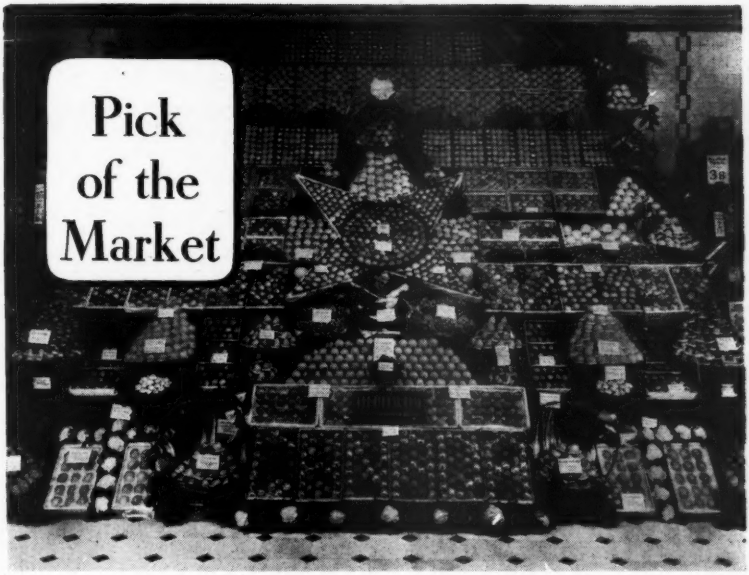
The tilting equipment is operated by an electric motor and a gearbox with several countershafts and racks situated below the live-roller bed. The pinion bearings must withstand a load made up of the weight of the material being rolled, tilting tables, racks and guides, as well as tooth pressure arising during operation. Peak loading amounts to about 303 tons, and this has to be carried by two bearings 500 mm. dia. and 440 mm. long (Figs. 6 and 7). The speed is 1.42 r.p.m., thus giving a sliding speed at the periphery of the shaft of 6.5 ft./min. and a specific pressure of 960 lb./sq. in. For each tilting operation the shafts rotate 11 times forward and in reverse. Tilting of the slabs is usually carried out only once during rolling.

The bearings referred to are in plastics which assist considerably in damping the shock and vibration occurring during tilting. In operation, the surface of the shafts becomes highly polished, and hence the formation of a lubricant film is more favoured than in cases where metal bearings are used. No seizing can occur between bearing and shaft.

The plastic used is a cellulose-wool laminate, the bearing being built up of five segments in order to attain optimum fibre position and to save material. Segments are assembled by means of screws and circular pressure plates. Ample side clearance is provided. It is interesting to note that the design is such that various bearing materials may be fitted for experimental purposes. For example, sintered iron bearings. Lubrication is by means of a hand pump.

The second countershaft is 300 mm. dia. and 390 mm. long. This also runs in plastic bearings. Sliding speed is 22 ft./min. and peak specific pressure 390 lb./sq. in.

No excessive wear was found, lubrication was satisfactory and no hot running was reported. For a fuller account of this mill see Arens, " Kunststoffe," 1942/32/237.



THE colourful displays of orchard fruits which were such an attraction of pre-war days have temporarily given way to those of drab but more sustaining foods. In the Plastics industry however, moulders and manufacturers still have a wide choice of all types of materials required for essential work. The range of I.C.I. (Plastics) Ltd. includes "Mouldrite" phenol formaldehyde type and urea formaldehyde type powders, resins and syrups; "Perspex" acrylic resin sheets; "Diakon" acrylic resin moulding powder; "Welvic" polyvinyl chloride compounds, nylon monofils, etc., etc.

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P.119

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The Scope of Plastics in Automobile Engineering

By D. Warburton Brown, A.M.I.A.E., F.I.P.I.

DURING the two years immediately preceding the outbreak of hostilities, the automobile industry was beginning to become aware of the possibilities offered by plastics, and many of the larger firms had begun tentative experiments. In the main these experiments were confined to body fittings and small unstressed components. This was natural because, generally speaking, the automobile engineer knew very little about the subject of plastics and had to proceed very cautiously.

The war, however, has engendered a great deal of intensive research work on plastics owing to their potential use in the construction of aircraft, and there is now available a wealth of data regarding the physical properties of these materials and their behaviour under alternating stresses. In addition to the laboratory work much valuable information has been gained from aircraft parts operating under service conditions. New materials have emerged and new and improved manufacturing techniques have been perfected.

When hostilities cease, therefore, and the industry is able to turn from war production to its normal peace-time activities, automobile engineers will have access to a great deal of relevant data concerning the use and behaviour of plastics and they will be able to contemplate the use of these materials with a confidence which they have never before been able to feel.

It is well realized that in the post-war period the manufacture of motorcars will be, more than ever before, governed by the economics of production, and that it will be this factor alone which will determine the materials and manufacturing methods which will be adopted. This article, however, will not be concerned with the economics of the business, but will give an indication of the scope which will exist for the use of plastics applied to automobile construction so that designers can consider their use together with other materials.

The question can be considered under the three main headings:—

(a) engine unit,
(b) chassis units, and
(c) body and fitments.

And the application of plastics to these units will now be dealt with separately.

(A) The Engine Unit

Those components on the engine unit will be called upon to withstand comparatively high temperatures as well as the normal vibrating loads, and because of this only those plastics in the thermo-setting group can be considered; there is one exception to this, but this will be dealt with later. In general, therefore, the materials which may be considered for engine components are (a) phenol formaldehyde, (b) phenol furfural, (c) urea formaldehyde.

In this connection it should be noted that these materials are available in various forms which include moulding powders, paper and fabric base laminates and extruded sections, all of which have their own applications.

A list of engine components which are suitable for consideration in plastics is given in Table 1. Some items are, of course, already manufactured.

Table 1.

Cylinder-head cover	Water-pump impeller
Tappet cover	Water-pump cover
Oil-filler tube and cap	Carburetters
Oil-pump body	H.T. leads
Oil-pump gears	H.T. conduit
Distributor cap	Camshaft bearings
Rotor arm	Main bearings
Pulleys	Connecting-rod bearings
Timing wheels	Cover plates
Fans	Commutators

Cylinder Head Cover

This component can conveniently be produced as a phenolic moulding or as a laminated moulding. A point to be borne in mind in connection with the use of plastics for this part is that all the plastic materials provide very good sound insulation.

Cylinder-head covers have been produced for one well-known firm of motor-car manufacturer, but it is not known whether this moulded component passed to the production stage. Provided the general shape of the component is straightforward the author is of the opinion that a full fabric base laminated phenolic moulding would give the most satisfactory results and would withstand the effects of temperature and hot oil satisfactorily and would be light.

Tappet Covers

Because of their straightforward form tappet covers make an excellent subject for moulding, and in this connection a laminated moulding in a coarse fabric phenolic material would be ideal. The remarks regarding sound insulation properties which were made in the section dealing with cylinder covers apply equally well in the case of tappet covers.

The use of a straight powder moulding in a semi-shock-resisting material has one advantage over a laminated moulding, namely, all the securing holes can be produced in the moulding operation and the component will need only hand finishing.

Oil Filler Tube and Cap

Oil filler tubes can satisfactorily be considered in extruded phenol-formaldehyde material or, alternatively, in laminated tube. The former tends to be rather brittle, but if suitably supported there is no reason why any trouble should be encountered.

Oil filler caps should be produced as phenolic mouldings, any screw threads or fixing devices (such, for example, as a bayonet-type fixing) being moulded in. In some cases, however, it may prove to be an advantage to use a metal insert for the threaded portion.

Oil Pump

The oil pump offers several possible applications, and just prior to the war

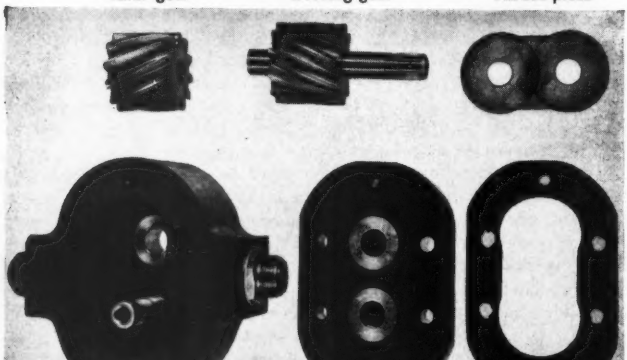

Fig. 1.—Experimental oil pump made up with plastic mould body, etc.

the author carried out a number of tests to determine the suitability of plastics for this unit. For the purposes of the test an oil pump was made up having a moulded bakelite body and cover and one gear (the idler) machined from a fine fabric base laminate.

This experimental pump (Fig. 1) was at first run with two steel gears and completed satisfactorily a total of 450 hours running under the following test conditions:—

Pump speed = 2,000 r.p.m.
Pressure (running) = 25 lb./sq. in.
Oil temperature = 75 degrees C.

At the end of this period the pump body was found to be in excellent condition and was rebuilt, after inspection, incorporating an idler gear made from laminated material, and a further 200 hours' testing was carried out under the same conditions. At the conclusion of the test it was found that apart from a slight swelling the gear was in good condition and that the " scruffing " of the walls of the moulded body was no worse than that normally found using an aluminium casing with steel gears. It was subsequently found that the swelling of the gear could be overcome by subjecting the material to a stabilizing process before final machining.

The conclusion arrived at as a result of these tests was that a pump designed on these lines would show advantages in respect to cost, quiet operation and weight, and would be reliable in service.

Distributor Cap and Rotor Arm

These items are now produced from a high dielectric grade of moulding powder as standard practice so that no further comment is needed. Another small but important application of plastics in the distributor is the rubbing pad on the contact breaker arm. This is now always made from a fabric base phenolic laminate.

Pulleys and Timing Wheels

Pulleys for fan belt drives can be satisfactorily produced from laminated phenolic materials having a medium or coarse fabric base. Pulleys made from these materials are now extensively used in the construction of aircraft and typical examples are shown in Fig. 2.

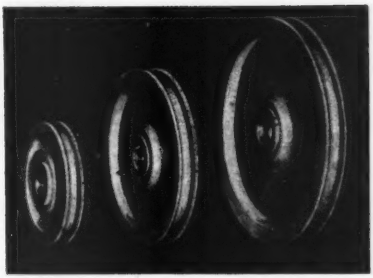

Fig. 2.—Pulleys in laminated material.

In search of quiet gear drives automobile designers specified rawhide gears for the timing train on engines. Later rawhide was replaced by fine fabric laminated phenolic plastics and now it is standard practice to use gears of this type. Chain wheels are also made from these materials and a typical example is shown in Fig. 3.

Water Pumps

The impeller for water pumps is a suitable subject for moulding, and in America before the war impellers had been produced as phenolic mouldings with the spindle integral with the impeller. These impellers which were made from a water resistant grade of moulding material have proved to be very successful in service, being particularly free from corrosive attack which is sometimes encountered when using metal impellers.

Apart from the impeller the cover plate of the pump might well be considered as a powder moulding.

Carburetter Parts

The carburetter offers several possible fields of application for plastics. The main body of this component is probably too complicated owing to the large number of internal passages, but the float chamber, float chamber cover, choke tube, and, in the case of the S.V. type of carburetter, the piston and cylinder, are all worthy of consideration. Another

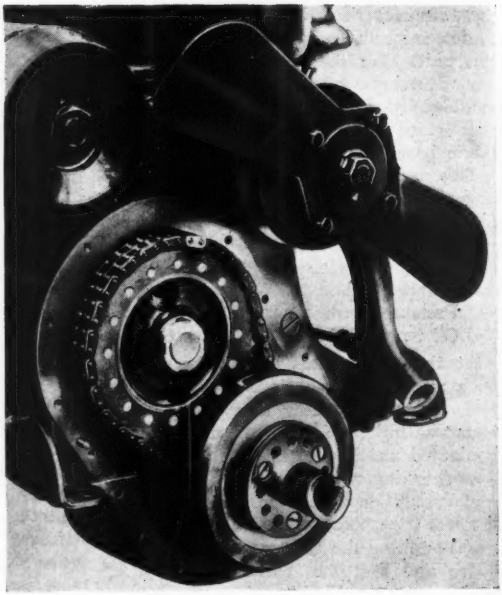

Fig. 3.—Automobile timing wheel of laminated phenolic.

possible component on this unit is the cover for the air intake.

H.T. Leads and Conduits

Earlier in this article it was stated that there was one exception to the general statement that only thermosetting plastics can be considered for engine parts, and that exception is the use of a thermoplastic of the polyvinyl chloride for H.T. cables. Electrical cables having a covering of this type of plastic extruded round the wire have several advantages to offer over the normal rubber-covered H.T. leads. These advantages include very high abrasion resistance, immunity from attack by oils and petrol, as well as enhanced electrical insulation.

Conduits for H.T. leads can be moulded if a special shape of conduit is required, or, if the engine layout permits the use of a straight tube, an extruded phenolic section can be employed quite satisfactorily. In order to keep the length of leads down to a minimum, thus reducing the risk of cable faults, an arrangement similar to that shown in Fig. 4 could be employed.

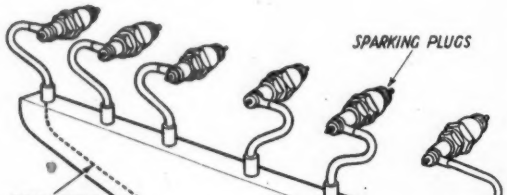

Fig. 4.—Suggested H.T. conduit unit.

Bearings

The use of plastics for automobile engines has been the subject of a considerable amount of research work.

Very little success, however, was achieved by the earlier investigators. It was found that although plastic bearings could be used with success in roll mills, where the loads were high but the rotational speed low, they could not be employed where the shaft speed was high. This was because the high rubbing speed generated considerable frictional heat, and the extremely poor heat conductivity of the plastic did not allow it to become dissipated quickly.

Comparatively recently, however, a new type of high-duty plastic bearing was evolved by Continental investigators, and tests both on a laboratory bearing-testing machine, on aeroplane engines, and on cars have shown that the new type of bearing is very successful.

Briefly this type of bearing, which is capable of carrying loads of the order usually associated with crankshaft bearings, and which is free from the difficulties of thermal stressing, is made by winding several thin strips of resin impregnated fabric tape round the bearing journal, pressing to shape, firmly cementing to the metal foundation and subsequently hardening.

On a laboratory testing machine it was found that these "wrapped journal" bearings were capable of withstanding continuous loads of ± 3,500 lb. per sq. in., as compared with ± 2,100 lb. per sq. in. for plain cylindrical plastic bearings. The load capacity of the wrapped journal bearings could be raised to ± 4,250 lb. per sq. in. for short periods. In all the above tests the rubbing speed was 2,400 ft. per minute, and normal lubrication was employed.

Bearings of this type were fitted to a 6/30 h.p. Wanderer car for the purpose of road testing and after some 1,250 miles' running-in, the car was run at high speeds for 7,500 miles before the engine was stripped for inspection. At the end of the test the bearings and housings were found to be in perfect condition, the wear on the bearings being only .001 in.

These details have been given to indicate the possibilities offered by plastic materials as applied to main journal and connecting-rod bearings. A similar type could also be used for supporting the camshaft.

Covers

Moulded phenolic materials can be used for producing blanking covers of all types. Either powder or fabric base laminates will be satisfactory.

Commutators

Dynamo and starter motor commutators can be produced cheaply as moulded units instead of being built up from numerous components. Patents have recently been taken out jointly by a well-known plastics and electrical concern describing the method of moulding commutators in a fabric-base laminated phenolic material. Great quantities of such commutators have already been made and are giving satisfactory service.

(B) Chassis Units

In general the remarks concerning suitable types of plastics for engine components apply equally well to parts fitted to the various chassis units. Here, again, however, it is possible to use with advantage polyvinyl-chloride-covered cable.

Typical components are shown in Table 2 and each will be briefly examined in the following section of this article:—

Table 2.

Front-axle thrust washers.	Synchro-cones.
Front-axle swivel-pin bushes.	Covers.
Spring interleaves.	Cross-shaft bushes.
Steering-linkage bushes.	Pedal pads.
Fuse and relay boxes.	Cable conduits.
Cable-junction boxes.	Brake cylinders and pistons.
Battery boxes.	Clutch thrust pads.
Gearbox thrust washers.	

Thrust Washers

The ultimate compressive strength of the fabric base laminates ranges from 30,000 to 47,000 lb. per sq. in., which makes these materials suitable for use as thrust washers of all types. Lubrication is not essential, but it is desirable, even if the plastic material is impregnated with graphite, as it increases the life of the washer.

The author carried out a number of tests using laminated plastics for front

axle thrust washers on a car, and it was found that after many thousands of miles road testing these washers were functioning satisfactorily. In earlier tests trouble was encountered owing to a slight swelling of the plastic resulting in the steering becoming stiff. This difficulty was overcome, however, by subjecting the washers to a stabilizing treatment prior to fitting to the steering assembly. (See Fig. 5.)

The stabilizing treatment referred to above consisted of soaking the component

Fig. 5.—Front axle thrust washer in laminated phenolics.

in oil at 90 to 100 degrees C. for a period of 100 hrs.

Steering Bearings

Front axle swivel pin bearings made from laminated plastics were fitted to several cars of Continental origin just before the outbreak of war, but so far as is known none of the British manufacturers had fitted them. No details are known as to the behaviour of these synthetic resin bushes, but as they were fitted to production models it is probable that they had undergone thorough testing and had been found to give service at least comparable with the more normal metal bushes.

Drag link and track rod spherical bearings machined from laminated materials were tested by the author, and apart from early troubles due to swelling these behaved satisfactorily. In this connection it is interesting to note that Automotive Products, Ltd., have taken out a patent covering the use of moulded plastics for this purpose. The arrangement of this type of joint is shown in Fig. 6.

Spring Interleaves

A number of tests were conducted using thin sheets of graphite-impregnated fabric-base laminated material for spring interleaves and the low coefficient of friction of these plastics made them admirably suited for this purpose.

Relay Boxes, Etc.

It is now standard practice to use a moulded phenolic material for producing the various ancillary electrical equipment such as relay boxes, fuse boxes and cable junction boxes.

Battery boxes are in the main made from one or other of the bitumen base cold moulding compounds with the lids moulded in a general-purpose phenolic material.

Gearbox

In the gearbox the application of plastics is limited, but such items as thrust washers (already described in section dealing with front axle parts) and cover plates do afford possible components for consideration. In constant-mesh gearboxes another part worthy of thought is the synchro-cone, which in normal circumstances is made from one of the bronzes. Experience has shown that supercharger cone drives on aero-engines behave quite satisfactorily.

Bushes

Cross-shaft bushes in graphite impregnated laminated plastics could be used satisfactorily, the self-lubricating properties of these materials being an advantage. In this connection it is interesting to note that one firm of aircraft engineers has patented a self-aligning bearing for

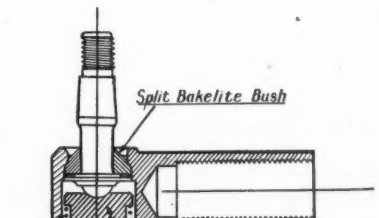

Fig. 6.—Details of steering joint using plastic bearings. (B.P. No. 493472, Automotive Products, Ltd.)

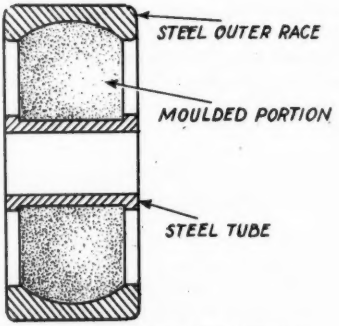

Fig. 7.—Self-aligning plastic bearing.

use in the control layout. This bearing which is shown diagrammatically in Fig. 7 consists of a steel sleeve and steel outer race with a bush of graphited moulding material of the phenolic moulded " in situ."

Cable Conduits, Etc.

The newer techniques of extruding polyvinyl-chloride covering over electrical cables offer interesting possibilities in the field of electrical wiring of motorcars. It is now possible to obtain extruded sections containing several cables (see Fig. 8), and it is felt that the judicious use of such cables in conjunction with moulded junction boxes would do a great deal to simplify the electrical layout on cars. In this manner, by virtue of sectionalizing the layout, the problem of fault location and cable replacement would be rendered more simple than in the case of the complicated " harness " system which is at present used.

The excellent abrasion resistance of the extruded polyvinyl-chloride covering would provide adequate protection against flying road chips, etc.

Brake Cylinder, Etc.

In hydraulic brake systems the wheel cylinders and pistons can be considered in a shock-resisting grade of phenolic moulding material as can the piston in the master cylinder. A further possible application of plastics to the braking system is the use of moulded polyvinyl-chloride seals and gaiters to replace parts now made from rubber.

Clutch Thrust Pads

Experiments have been conducted to determine the suitability of fabric base laminated phenolic plastics for use as clutch thrust blocks instead of the more normal graphite block. So far as the author is aware this application has given satisfactory results over many thousand miles' road testing.

(C) Body and Body Fittings.

In the immediate pre-war period the use of plastics by the automobile industry for production purposes was largely confined to the body fitments. The high finish and large colour range of the synthetic resin materials made them very suitable for decorative mouldings, ash-trays, etc.

It is not proposed to deal at any length with such applications, but Table 3 will indicate some typical body parts which were to be found on production models before the war.

Table 3.

Dashboards	Steering wheel covering
Window frames	Gear shift knobs
Decorative motifs	Control knobs
Interior lamps	Trafficators
Ashtrays	Switches
Door handles	Tail lamps
Heater grilles	

The question of producing the complete body from plastics received a good deal of thought, but in this country little real progress was made in this direction. In America, however, Ford followed the problem to the practical test stage and produced a number of experimental cars with completely moulded bodies. There has been a good deal of speculation as to

Fig. 8.—Typical cables with extruded polyvinyl-chloride covering.

whether a body of this type will ever prove to be a serious competitor of the all-steel unit.

The subject of moulded body construction was dealt with more fully by the author in a previous article ("Plastics"—January, 1943) and it is felt that whereas Ford may be able to produce a moulded body on a commercial basis in America by virtue of the large markets catered for, it is very doubtful whether a plastic body could be made economically in this country. The use of moulded plywood, however, appears to offer certain possibilities.

There has been from time to time speculation as to whether the transparent methyl methacrylate plastics can ever be used for windscreens and windows. At present these plastics do not possess a sufficiently hard surface to resist the abrasion of road grit (especially under the action of a windscreen wiper). Recently, however, a patent was taken out in America for protecting the surfaces of plastic lenses by means of a very thin film of glass applied to the plastic surfaces, and it may be that suitably developed this process could be used for producing windscreens, etc. Plastics of the cellulose acetate and vinyl types are of course used largely in the manufacture of safety glass.

It is also possible that the hard wearing properties of nylon will be utilized for upholstery in post-war cars.

SUBSTITUTE MATERIALS

(Continued from p. 188)

of saving aluminium, have become even scarcer than the metal they have replaced.

It may be regarded as certain that this group of industries will be greatly extended after the war, and this may have important results in determining the location of industry. As the production of plastics, a highly-developed branch of chemical industry, is not dependent on access to ores or special minerals, but may be carried on wherever power is available and either coal, petroleum or alcohol can be got, the provision of labour is the main determining condition, always supposing that adequate technical guidance is to be had, as the processes of manufacture and manipulation call for a high degree of scientific knowledge and skill. The plant is often complex, and makes new demands on the engineering industry. In comparision with metals, plastics are relatively costly, and have to justify their adoption by their superior properties and by the convenience of shaping into finished objects without machining.

He completes his review with the following remarks:—"Attention has recently been called to the rapidly increasing rate at which the ores of several of the metals essential to modern engineering, and such minerals as phosphates, so important to agriculture, are being exhausted. There is a wide field open for improvements in the economical use of these shrinking assets, by their recovery and re-use, and by the substitution of less extravagant alloys, etc. New techniques will have to be developed to meet these difficulties.

"In consuming mineral wealth the world is living on its capital, which once exhausted is not renewed, whilst products derived from agriculture and forestry may be regarded as coming out of income. A greater dependence on such renewable natural resources, made possible by advances in plant and animal breeding, in the use of micro-organisms for producing organic compounds, and in the conversion of such products into plastics, synthetic fuels, novel fibres, etc., may play an important part in the economy of the future. Vast areas of cultivable land are at present very imperfectly utilized, and developments of this kind provide the possibility of raising the standard of living of their inhabitants, and at the same time of augmenting the resources of the older industrial countries."—(Published by The Oxford University Press, price 9d.)

World's Industry Employs Plastics

GENERAL ENGINEERING

Protection of zinc is dealt with by Weise in "Techn. Zbl. prakt. Metallbearbeitung," vol. 51, p. 583. Pure cellulose-base lacquers are unsatisfactory as substitutes for oil-base paints; chlorinated rubbers give good results, but phenolic-resin base paints and vinyl resins appear to constitute the best all-round media. **Impregnation of castings with synthetic resins** forms the subject of an address by Rehbock before a V.D.I. meeting, and later summarized in "Kunststoffe," 1941/32/128. Polyvinyl chloride and polystyrene are considered the most satisfactory media for use in this connection. The techniques of solution-impregnation and molten-resin impregnation are noted; the use of monomeric styrene being examined in the light of the latter system, equipment for curing being described. The problem of shrinkage of the resin in the pores is noted, together with the fire and health hazards associated with styrene. **Design and lubrication of plastic bearings** form the subject of comment by Matuschek in "Fördertechn," vol. 32, pp. 261 and 385. It is observed that plastic bearing surfaces carrying loads should not be slotted for lubricating, in the case of highly stressed bearings in rolling mills. Loads should be applied as slowly as possible. For high-speed, lightly stressed bearings, ring-oiling is most suitable. Intermittently loaded, slow-running, heavy-duty bearings are best lubricated with Stauffers grease, viscosity being higher where prolonged runs are to be expected. The author concludes by discussing the design and manufacture of plastic gearwheels, noting especially the peculiar mechanical properties of the materials in relationship to this special application.

AIRCRAFT

Application of radio-frequency heating to speed industrial processes, and at the same time increase their efficiency is rapidly coming to the fore. Known as "thermal radio," it can be used for processing a laminated aeroplane propeller in a few minutes, cementing rubber, hardening metals, curing wood, "stitching" cloth, gluing plywood and performing countless other operations. **Pliofilm bags provide hermetically sealed enclosures for shipment of aircraft engines.** Bags are heat sealed mechanically to give a moisture-proof container until the engine is finally installed.—("Machine Design," March, 1943.) **Influence of low and high temperatures** on commoner types of plastics is dealt with by Delmonte in "Machine Design for March, 1943, vol. 15, p. 87. The effect of temperature is discussed in detail with respect to the following properties: tensile strength, punch strength, impact strength, elastic modulus, deflection and creep. As typical application of plastics to which this data might refer are quoted plastic baffles between cylinders of radial engines, and an aerial-mast base. **Laminated paper plastics, produced from a special wood pulp and phenolic resins,** are used in a new aircraft construction, developed by McDonnell

Aircraft Corp. in collaboration with Forest Products Laboratory. As a special advantage, it is claimed that the number of components can be so reduced that, in a special case, only 13 parts are used as compared with 96 when fabricated of aluminium. Wing tip ribs can be formed from impregnated paper blanks in one operation, as contrasted with 19 for plywood ribs of this type. Other advantages are: smooth surface (obviating finishing and coating), greater resistance to abrasion and denting than aluminium (?), adaptability to double curvature forms without special treatment, etc.—("Machine Design," March, 1943, p. 87.)

TEXTILES

Impregnation of textile fabrics with acrylic resins is discussed at length by Lachmann in "Chemiker Ztg," 1942/66/3; 24. The author considers first the purpose of such processing, then examines in detail various commonly used media, including the rubbers, lacquers of different types, drying oils and nitrocellulose. Synthetic-resin-base compounds are also touched upon. The particular merits of water dispersions of the acrylic resins are then reviewed, with special attention to the facility with which impregnation may be carried out, and to the economics of the process. The physical properties of treated fabrics are then examined.

ELECTRICAL

Electrical strength of commercial resin-impregnated papers and fabric laminates forms the subject of a detailed report by Pfestorf in "Kunststoff Techn," vol. 11, p. 252. In particular the author presents graphical and tabular summaries of his findings, and values parallel to and at right-angles to direction of lamination are noted. **Coverings for marine cables** form subject matter of abstract in "Gummi-Zeitung," vol. 54, p. 254. The disadvantages of ordinary thermoplastic resins are briefly considered, especially as regards their prolonged softening range. The use of vulcanized Buna and allied mixes is then commented upon. Requirements of undersea cables are summarized and shortcomings of synthetics as opposed to natural rubber noted.

CHEMICAL

Leather-like fabrics, impregnated with thiokol latex *in vacuo*, are stated by Weiler, in a dissertation before the Techn.-Hochsch at Karlsruhe, to be suitable as membranes in gas-measuring apparatus for laboratory and industrial use. The porosity of the fabric base influences the accuracy obtainable with any given membrane material, but results can always be assured within desired limits. Unlike other impregnating resins, only thiokol appears to offer prolonged resistance to the continued action of town's gas. (See "Kunststoffe," 1942/32/196.)

MISCELLANEOUS

Nomenclature and marking for improved timbers according to D.I.N.4076 are summarized in "Kunststoffe," 1942/32/129. The abstract includes also a grading system for glues and mineral adhesives applicable to woodworking techniques. **Rubber derivatives considered as plastics** are discussed by

Houwink in "Kunstoff-Techn.," vol. 11, p. 189. The derivatives are classified under the following headings:—Oxidation products; chlorinated rubber; rubber hydrochloride; rubber isomers. The properties and uses of each of these groups are then examined in the light of various industrial requirements, brief details being given of the manufacture of the specific materials. In conclusion, the author deals with rubber products obtained by treatment of the natural rubber with zinc chloride, boron fluoride, etc.; pliofilm and pliolite are referred to. It is observed that, so far, no industrial use has been found for the bromine and iodine derivatives of rubber. **Large, rotary fruit-juice extractors,** producing 200 gallons of citrus juice per hour, have been equipped with self-lubricating bearings of Lucite methyl methacrylate resin. After trials with other substitute bearing materials to replace bronze bearings, it was found that these bearings were lubricated by contact with citrus juices and steam, both of which adversely influenced the life of bronze bearings. The Lucite material is said to be equally resistant to orange, grape-fruit and lemon juices. **To increase production of nylon,** nylon salvage is depolymerized into the original two starting chemicals—adipic acid and hexa methylenediamine. To achieve this, scrap nylon is boiled in strong hydrolizing agents. After one hour's boiling, the original product has completely disappeared and the vessel contains only a dark bronze solution. A precipitate forms on cooling; filtering through glass wool separates this, which contains the adipic acid, from the filtrate containing the diamine. Each of the two components is now purified (see "Scientific American," for March, 1943). **A new plastic glass, C.R.39,** has been developed by the Columbia Chemical Division of the Pittsburgh Plate Glass Co. (according to "Scientific American," March, 1943, p. 124). It is claimed that it is insoluble in acetone, benzene, toluene, alcohol, gasoline, or any common solvents. Its resistance to abrasion is stated to be 10 to 30 times greater than other clear plastics. In its primary form C.R.39 is a clear, low-viscosity liquid, which, in the presence of a catalyst and heat, hardens into a crystal-clear solid. **Finger-plates and allied fittings** for office use are prepared by impregnating paper board with transparent urea resins and curing under pressure. By this process, sheets up to 3 ft. by 5 ft. may be manufactured, according to Wirth in "B.B.C. Nachr," vol. 28, p. 55. **Edge effect** is one of the most troublesome sources of error in interpreting photo-elastic patterns, hence, Walter Leaf, research technician of The Denver and Rio Grande Western Railroad Co., discussed this aspect in a research paper read before the recent Eastern Photo-elasticity Conference ("Machine Design," vol. 15, March, 1943, p. 109). He presents now, apparently for the first time, accurate data on the effects of atmosphere, material, and age of model, so that it is possible to evaluate the edge effect and to obtain more precise results. The investigation was carried out with Bakelite and Catalin. **New soil tester** has been developed, especially for use of Army engineers. The soil sample is enclosed in a thin rubber membrane, whilst the pressure chamber consists of a transparent plastic cylinder. This houses the sample, the pressure medium (water and nitrogen or water alone) and the proving ring assembly. Specially moulded rubber gaskets at top and bottom ensure water tightness.—("Machine Design," vol. 15, March, 1943, p. 94). **Protection of rayon or rayon-containing materials against depredations of an insect pest, the silver fish,** is described by Mantell and May in "Modern Plastics," for February, 1943 (p. 51). The authors conclude from their work that the insects are attracted principally by the finish; if this be absent, then the material becomes unattractive to them. By replacing starch finishes by urea formaldehyde finishes, any danger of attack is obviated, whilst, at the same time, the sales-appeal of the fabric is maintained, in so far as its non-creasing qualities are preserved.

Ultracentrifuge with Plastic Rotor

The following note by K. G. Stern has been published in "Science" (Vol. 95, 1942). Its main interest lies in the fact that the methyl methacrylate resin Lucite not only replaces metal but that it withstands the forces exerted on it under very high speeds

THE ultracentrifuge constructions presently in use are based either on the principle of the oil-turbine velocity centrifuge, equipped with mechanical bearings and a vertical steel rotor, or on the principle of the bearing-less "spinning top," which represents an air turbine floating on a cushion of compressed air. The analytical centrifuges of McBain and the concentration and optical centrifuges of Beams, Wyckoff and Pickels and Bauer are derived from the latter type. The most frequently employed rotor material in these constructions is duralumin.

During a recent visit to the Svedberg centrifuge laboratory of Professor J. W. Williams at the University of Wisconsin, it occurred to the writer that the use of materials of very low density for the construction of ultracentrifuge rotors might result in a considerable simplification of centrifuge design and obviate the necessity of employing expensive steel and aluminium alloys which are now difficult to procure on account of the National war effort. The first trials were made in Madison with 0.5-in. thick discs of polystyrene and of polyacrylic, transparent resins of 1.5 and 2 ins. dia. respectively. With the mechanical assistance of Messrs. E. Hanson and L. Henke these discs were transformed into simple air-turbines. Employing a 2-in. Lucite disc, tank nitrogen as propellant and a primitive optical set-up with a spectacle lens as objective, the sedimentation of aggregated earthworm hemoglobin within the cylindrical fluid cell was photographed with the help of Mr. Ch. Vilbrandt. Since the Lucite turbine showed no signs of irreversible deformation, even when spun for 10 mins. at approximately 40,000 r.p.m., the writer felt encouraged to continue these experiments with plastic rotors after his return to New Haven. A 2-in. Lucite turbine was accelerated to 57,000 r.p.m. with the aid of 80 lb./sq. in. air pressure as measured with the Kahler-Hunt photoelectric speed-measuring circuit. After the mechanical features of the centrifuge had been improved in various respects, the construction of a 6-in. plastic turbine was undertaken with the mechanical aid of Mr. H. Nelson. Throughout the later phase of this work much benefit was derived from the expert advice of Professor F. W. Keator, of the Department of Mechanical Engineering, and several

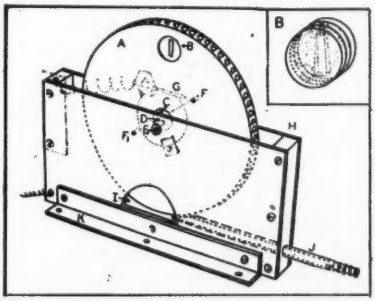

Fig. 1.—Air-turbine ultracentrifuge with plastic rotor. A, Lucite rotor, 0.5 inch thick, 6 inches diameter, with flutings milled into the periphery; B, analytical fluid cell (see below), inserted in cylindrical cell hole; I, semi-circular opening in casing, H, to permit free escape of expanded driving air; J, air-jet. Insert B, analytical fluid cell, made by cementing, with Lucite cement, two outer discs of colourless Plexiglas resin to central disc of red Plexiglas.

RUBBER INTO PLASTICS

Cups for collecting Latex from rubber trees have, of course, been made of many materials—cocoanut shells, metal, glass, earthenware. The interest in this new Latex cup, which is a very simple moulding in Beetle produced for The United Africa Company, Ltd., lies in the strange reversal of circumstances which have called in synthetic plastics to help production of one of the oldest of natural plastics.

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improvements, based on his suggestions, were incorporated in the design.

A schematic drawing of the centrifuge at its present stage of development is reproduced in Fig. 1.

The top speed thus far attained with this model has been 17,400 r.p.m. at 48 lb./sq. in. air pressure and an estimated free flow of 40 to 60 cubic ft./min., yielding a force of 20,200 times gravity at the centre of the analytical fluid cell which is situated at a distance of 6 cm. from the centre of rotation. This speed is sufficient to cover practically the entire size range of plant and animal viruses as given by Stanley,* and, in general, to bring about molecular sedimentation, at appreciable rate, of protein particles from about 10^6 molecular weight upwards. As examples of such materials, the sedimentation of earthworm hemoglobin and of Stanley's crystalline tobacco virus protein, with sedimentation constants of $s_{20} = 60 \times 10^{-13}$ and 175×10^{-13} and molecular weights of 3×10^6 and 40×10^6, respectively, has been photographically recorded employing the 6-in. Lucite rotor.

The definition of the sedimenting boundaries, as exemplified in the results, the regular rate of sedimentation during the individual intervals, and the values of the sedimentation constants obtained for the virus with this centrifuge ($s_{20} = 157$ and 161×10^{-13}) as-compared with that determined in our Beams ultracentrifuge ($s_{20} = 175 \times 10^{-13}$) for the same preparation, may be regarded as evidence that sedimentation in the plastic rotor proceeds essentially undisturbed by mechanical vibration or thermal convection currents.

The plastic rotors may be adapted to use in centrifuge microscopes as well as in analytical ultracentrifuges. The contact arrangement indicated in Fig. 1 (parts F and G) has been used to synchronize a stroboscopic light source (e.g., Strobotak of the General Radio Company) with the rotor and to examine living cells during centrifuging with a low-power microscope.

* W. M. Stanley, "Handb. d. Virusforschg.," p. 538, Vienna, 1938.

PLASTICS IN THE WRIGHT CYCLONE ENGINE

"Machine Design" of February, 1943, reports that plastics replace two sheet aluminium parts in the Wright Cyclone engine (right), effecting a saving of many thousand pounds of the vital metal monthly, giving twice the service life of the parts involved and providing reductions in engine weight, manufacturing time and costs. The two parts—baffles or air deflectors and push-rod housing—are in quantity production and other manufacturers are expected to adopt them as standard. Made in one instead of five operations the parts are fabric impregnated with phenolic resin and are formed in moulds and cured under heat and pressure. The baffles deflect the air stream over the entire finned surface of the cylinders, providing rear bank cylinders with the same cooling as the front. The push-rod housings, 1-in. tubes about 12 ins. long, protect the push-rods and act as a return channel for oil carried to the entire valve mechanism.

It is not clear that the moulding is of the conventional type, and may refer to curing fabricated tubes on a mandril.

The Wright Cyclone engine in which are clearly seen the tubular push rods.

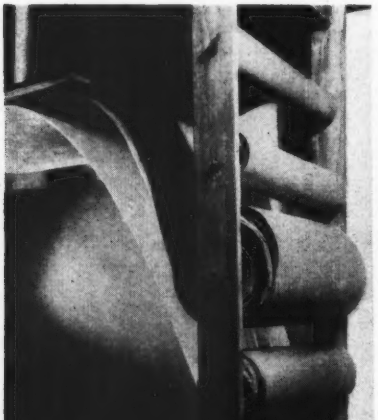
Aircraft Parts of Resin-impregnated Paper

The adoption of resin-impregnated paper in the U.S.A. for small aircraft parts, while not an unknown technique here, is interesting as a corollary to the so-called plastic aeroplane of laminated plywood

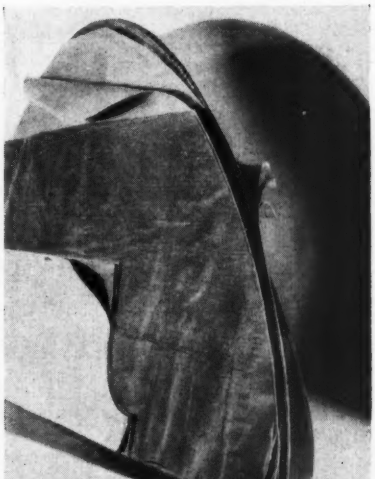
By H. W. PERRY

SEVERAL important advantages over metal and plywood as aircraft, structural materials are claimed for laminated plastic-impregnated paper, which has been used experimentally by the McDonnell Aircraft Corp., of St. Louis, Missouri, U.S.A., in the production of numerous minor and some major aircraft structures. Besides the saving of considerable aluminium and steel required for air-frames, engines and other military products, laminated-paper parts can be made faster than the parts can be fabricated in metal, with less, lighter and cheaper equipment, with a reduction in man-hours of work and with slight waste of materials which are relatively plentiful and available.

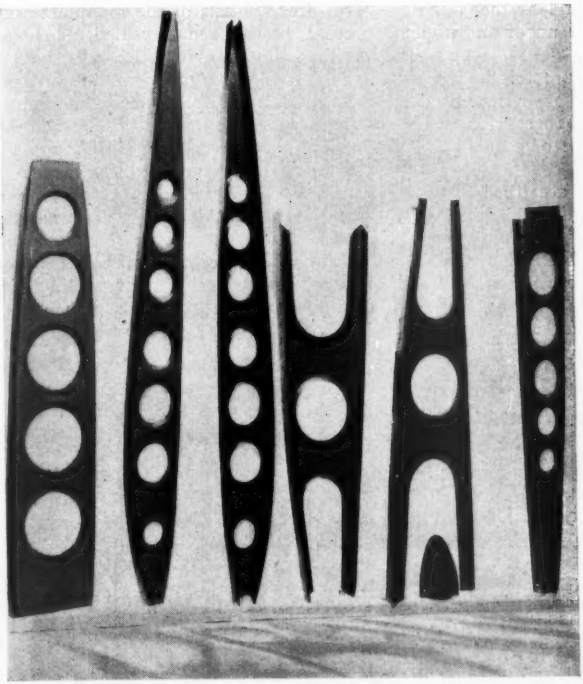
Moreover, gauge thickness can be graduated according to magnitude of stresses likely to be imposed on different sections or areas of a part, the strength/weight ratio is even higher than that of corresponding parts made of aluminium, the plasticized paper can be moulded readily to compound curvature without special treatment, the shaped structure presents a smooth surface which needs no finishing and no protective coating, and



Rolls of plastic-impregnated paper sheet arranged for convenience prior to laminating.



Wing-tip blank cut from paper layers decreasing in number towards tip to taper the gauge.



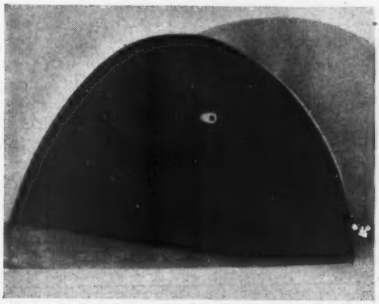
Laminated paper ribs of the wing tip moulded at a pressure of 250 lb./sq. in.

it has greater resistance to denting by impact and to abrasion than has aluminium sheet.

In the work done in this field the McDonnell Company has had the co-operation of the pulp and paper section of the Forest Products Laboratory of the U.S. Department of Agriculture, and also of a paper manufacturing company in producing a strong paper from a special wood pulp and impregnating the paper with a liquid phenol-formaldehyde plastic at the mill.

The impregnated paper comes to the aircraft plant in rolls which are there placed horizontally in a vertical wood frame for convenience in unrolling to form laminations. To produce a tapered gauge, some sheets are drawn farther out towards the end than others, thus reducing the number of plies, as in making the skin of a wing tip, here illustrated, which is thinner at the outer edge than at the attaching edge for increased lightness.

Next, from the paper laminations a blank is cut to profile of the intended part and placed in a press over a die having



The finished wing tip on only 15 parts compared with 96 parts for the conventional aluminium tip of the same size and design.

the correct contour. Here the skin is moulded in single-piece upper and under halves at a pressure of 250 lb./sq. in. in zinc-alloy dies, which are relatively soft and readily melted for repeated die making. Truss-type, flanged ribs of the wing tip also are made of paper in the same way.

A wing tip made as described consists of only 15 parts as against 96 fabricated parts in a conventional aluminium tip of the same design. One bolted horizontally to a vertical stand sustained a static load of 2,800 lb., which is 40 per cent. more than the design load for a metal tip.

No other details of the manufacturing process have been revealed, such as whether liquid synthetic adhesive is applied when laminating the paper, whether heat is applied during moulding, time required for the plastic to set in the press so that parts are rigid enough for handling, and how the skin is bonded to the ribs. Neither has information been given as to the kind of wood used for making the paper or the thickness and physical properties that make the paper especially suitable for impregnating and moulding into aircraft parts. Such data are important for future work.

Joining Light Alloys with Adhesives

Brief Details are Given of a New Technique Employing a Plastic Adhesive for Making Metal-to-Metal Joints. The Results of Some Mechanical Tests on Duralumin Sheet of Various Gauges are Detailed

IT is now possible to publish* some details of the Redux process,† which provides, through the use of synthetic resin adhesives, a method of bonding light alloys to light alloys and steel to steel with a strength exceeding, under certain conditions, that of riveting. The process is also capable of giving strong joints between metal and wood, a constructional device of rapidly growing importance in many spheres of interest, both in military and in non-military engineering practice.

This wide extension in the field of resin bonding opens up new possibilities in the sphere of aircraft construction and introduces further valuable assembly possibilities to the engineering and industrial designer.

The development of the process may prove to be as significant as the introduction of the resin adhesives generally, which within recent years have revolutionized the plywood industry.

Basically, the process is a method of resin-bonding applied by a technique involving accurate control of variables, but adaptable to the nature of the surfaces to be joined and to the character of the structure to be assembled.

It enables light alloys and steel to be cemented together or to wood without stress concentrations, to give joints which are aero-dynamically smooth, petrol-tight and stronger than comparable riveted joints. It also gives strong joints between metal and wood, and is essentially economical and lends itself to modern production methods.

Metal-to-metal Bonds

The synthetic resin adhesives used are unaffected by water, oil or petrol. The process works best with trivalent metals, such as aluminium (duralumin), chromium and iron or steel; it gives less satisfactory joints with brass, tin or zinc. The resin bond is mildly thermoplastic and loses strength at temperatures above 100 degrees

* By Permission of M.A.P. The Redux process has been declared secret by the Government and, at present, is available only to concerns engaged on essential war work.

† Aero Research, Ltd.

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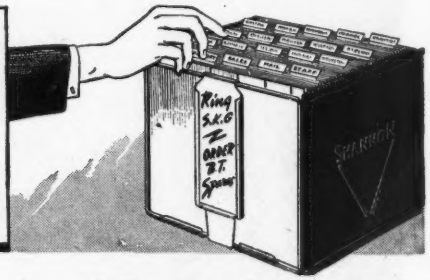

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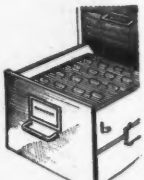

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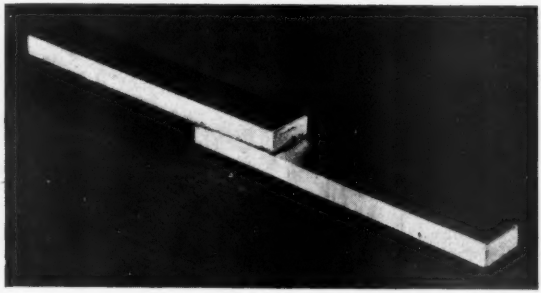

(At the left) Duralumin lap-joint test piece used for the shear strength determination referred to in the two remaining illustrations on this page. The joint is made with Redux in two strips of duralumin 0.2 in. thick, 0.45 in. wide, with a lap of 0.9 in. Below are seen the two units of the joint after breaking in shear (1.7 tons per sq. in.).

C. The loss of strength is, however, regained on subsequent cooling provided that the joint has not been subject to undue strain while in the heated state.

The softening temperature referred to is sufficiently high for aircraft use where, by the elimination of riveting practice with its attendant formation of broken surfaces, the method provides smooth surfaces having distinct aerodynamical advantages.

Shown above is an enlarged view of part of the adhesion surface of the joint referred to in the two other illustrations on this page. It will be seen that rupture has taken place at the plastic surface; no tearing of the duralumin surface appears to have occurred. Incidentally, it may be noted that the roughened surface shown here is not essential to good adhesion.

Metal-to-wood Bonds

The process gives strong joints between metal and wood, and meets design requirements arising out of existing trends in aircraft construction. It solves, for example, the troublesome problem of attaching steel fittings to the root ends of wooden spars.

Other uses are found in the local reinforcement of wood where concentrated loads have to be applied to a structure. In such cases it is often convenient to cement the metal to a plywood facing by this system, and then to cement the plywood-metal com-

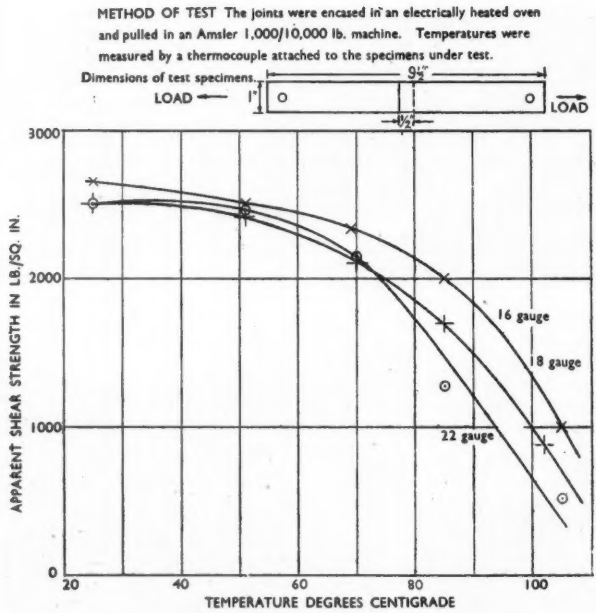
METHOD OF TEST The joints were encased in an electrically heated oven and pulled in an Amsler 1,000/10,000 lb. machine. Temperatures were measured by a thermocouple attached to the specimens under test.
Dimensions of test specimens.
LOAD
LOAD
APPARENT SHEAR STRENGTH IN LB./SQ. IN.
TEMPERATURE DEGREES CENTIGRADE
16 gauge
18 gauge
22 gauge

Fig. 1.—Details and curves of shear test on lap joints in alclad, 1 in. wide with ½-in. overlap. Joint was tested in 22 g., 18 g. and 16 g. thickness material, at temperatures from 20-110 deg. C.

ponent to the aircraft structure with a cold-setting adhesive such as Aerolite 300 with Hardener GMB or GBP.*

Strength of Redux Joints

Fig. 1 shows the results of tests on simple alclad lap joints 1 in. wide, with ½-in. overlap of 22 g., 18 g. and 16 g. thickness, pulled at various temperatures in an Amsler 1,000/10,000 lb. testing machine.

The strength increases somewhat with thickness of the strip, because, when pulled, such a joint is subjected to bending as well as shearing stresses; the greater stiffness of the thicker gauge strips reduces the bending and causes the load to approximate more and more to pure shear. Thus (see Fig. 2) when 6 g. strip is used the apparent shear stress rises to 5,300 lb./in.² at room temperature.

It will be seen that with the gauges commonly used in aircraft, the failing stress exceeds 2,000 lb./in.² at temperatures up to 70 degrees C. Redux joints do not become brittle at temperatures below freezing point.

* Aero Research, Ltd.

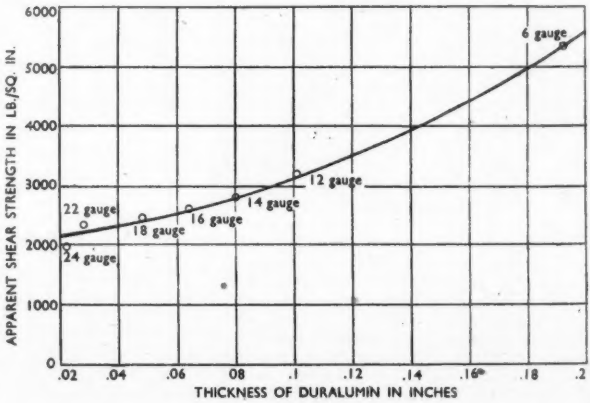

Fig. 2.—Curve showing effect of thickness of material joined on apparent shear strength of joint. It will be observed that thicker material gives a joint of increased strength.

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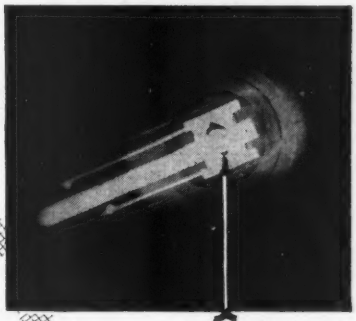

Radiograph of moulded assembly showing incorrect location of metal insert.

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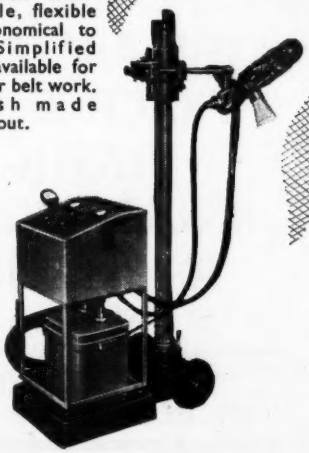

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PRODUCTION NEWS

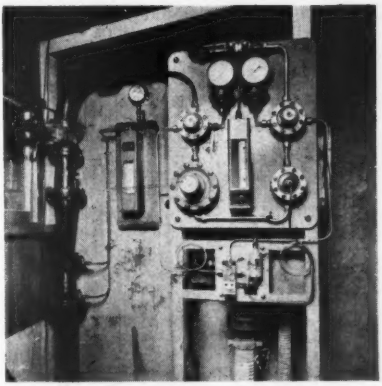
Raw Materials, New Plant, Works Organization, Control Apparatus, Research, Personal and Trade Notes

STERILIZATION OF COOLING WATER.—One of the troubles in the use of cooling water is the gradual growth in the pipes, coils, jackets, condensers, and similar spaces, of organisms, chiefly of the algae and protozoa types, which form a slimy deposit. This possesses pronounced insulating properties, so that the efficiency of the cooling water is thereby reduced to a serious extent, while in bad cases the deposits multiply to such a degree as to cause choking and irregular circulation of the water. The trouble also varies, depending for example upon the atmospheric temperature, being as a rule worse in summer than in winter, because of the more luxuriant growths of the organisms.

The remedy is treatment of the cooling water with a measured trace of chlorine gas on the lines that is now standard scientific practice for turbine condensers and cooling towers at power stations. In this connection organic deposits are so serious that they soon cause a reduction in the degree of vacuum obtained at the turbine condenser, and, for example, 1 in. (of mercury) drop, from, say, 29 ins. to 28 ins., causes on the average an increase of about 5 per cent. in the coal bill. Probably more than 500,000 tons of coal are being wasted in Great Britain in power stations alone because of organic growths, although many stations, as already indicated, are equipped with chlorination plant.

The pioneers in this field are the Paterson Engineering Co., Ltd., of London (Windsor House, Kingsway, W.C.2), who, in 1922, equipped the first plant in the world, at a well-known London power station, for the treatment of cooling water with chlorine to prevent organic growths. Since this date they have equipped many power stations both at home and abroad, but it is not generally realized the method is of great value for industrial cooling water, in conjunction with, for example, refrigerators, cooling coils, jacketed pans, with water-cooling, air compressors, internal-combustion engines, general condensers for distillation, and similar plant, and, of course, steam engine and turbine condensers of any size.

For this purpose the firm use their well-known "Chloronome" equipment, available in different types, which, however, are all on the same principle, being essentially a metal panel with control valve, pressure gauges, metering device, filter for the chlorine, moisture seal, and two pressure-reducing valves in series, coupled up with a supply of chlorine either in drums or

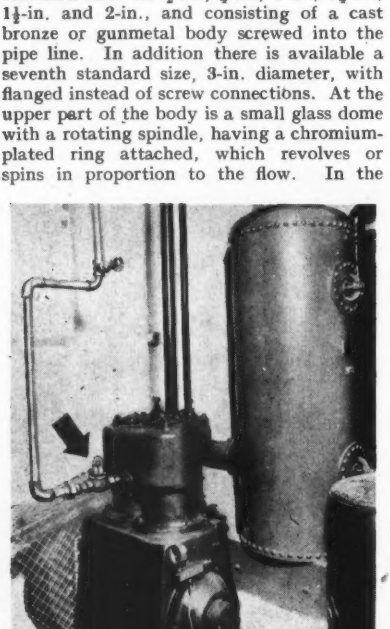


cylinders by narrow-diameter flexible copper tubing. In this way the chlorine gas is admitted continuously at any desired pressure rate, passing into a small stoneware tower forming part of the equipment to make a comparatively strong solution of chlorine in water, which is then discharged to the cooling-water circuit, ensuring rapid and uniform mixing.

While conditions differ, roughly 0.5 part of chlorine is required per 1,000,000 parts of water, and equipment is available for dealing with as little as 0.4 lb. of chlorine per hour. This industrial equipment is equally important for the sterilization of sewage and sewage effluents, and installations are at work of very large size up to 150 lb. of chlorine per hour. Another application also is sterilization of the washing water for fruit and vegetables before canning and bottling.

COOLING WATER CONTROL.—In connection with the use of cooling water for air compressors, both small and large, it is

necessary to have some method of indicating at a glance that the full flow of the water is always maintained in the pipe circuit. For this purpose of particular value is the "Arkon" liquid flow indicator, a production of Walker Crosweller and Co., Ltd., of Cheltenham (Glos), supplied in six standard sizes for ½-in., ¾-in., 1-in., 1¼-in., 1½-in. and 2-in., and consisting of a cast bronze or gunmetal body screwed into the pipe line. In addition there is available a seventh standard size, 3-in. diameter, with flanged instead of screw connections. At the upper part of the body is a small glass dome with a rotating spindle, having a chromium-plated ring attached, which revolves or spins in proportion to the flow. In the



casing is a small horizontal cast bronze impeller operating the vertical steel spindle, and the instrument is suitable for pressures up to 40-50 lb. per sq. in., although the dome, of specially toughened glass, is tested hydraulically up to 500 lb. per sq. in.

The instrument can be fixed in the pipe circuit at any desired point, although it must be horizontal, and the revolution of the ring is visible at a considerable distance because of the "breaking" action of light. That is to say, it is not necessary to peer into dark corners, or climb into awkward positions to find out whether the flow is taking place. Further, the instrument cannot seal or block the pipe, whilst the glass dome stands well clear of the liquid flow, and is therefore not obscured by dirty water. In this connection also cleanliness is very seldom required. In addition, the propeller can be supplied for either low or high velocity of flow.

Apart from air compressors, the instrument is finding a wide use in many other sections of engineering, and some typical examples are for the cooling water circuits, bearings (especially fans and heavy machinery), presses, electric welding sets, degreasing plants, furnace electrodes, boiler circulating pumps, radio transmitters, and emulsifying equipment.

Another important general application in which failure of the cooling water supply may have particularly disastrous results concerns the operation of mechanical stokers and pulverized fuel plants for coal, as well as water-cooled furnace bars and tubes in contact with combustion chambers. Here surfaces are exposed to direct heat from a combustion chamber, and a continuous flow of cooling water is of vital importance as regards the prevention of burning out.

PLASTICS IN SOUTH AFRICA

THE general shortage of crockery, glassware, etc., is helping to develop the South African plastics industry, which should be able to serve many of the country's needs after the war. The South African Railways are now using plastic tumblers made in South Africa in the dining-rooms, restaurants, dining cars and elsewhere on the trains. These are taking the place of glass tumblers, supplies of which are difficult to obtain. Many other sorts of plastics are now being made in South African factories, and included in their products for which there is now an increasing demand are all types of motorcar and lorry battery. Moulding powders for plastics are being made in the Union under branded names.

At the same time there is still more importation of British plastic products, and among such to make a recent appearance on the local market is a series of small magnifying glasses with plastic cases. They are proving of value for many different purposes in South Africa, particularly in engineering works, for map-reading, deciphering blue prints, etc. There will be a much bigger sale of this product when shipping facilities are rather better than at present.

A new company called Plastic Manufacturing Co. of South Africa has begun the manufacture of a number of important plastic products in Johannesburg. Among these products are dielectric material in sheets, rods and tubes, also plastic containers for pharmaceutical and toilet preparations.

Another Johannesburg firm (Hutt and Nelson, 19, Meikle Street) claims that in the field of plastics it has made great strides and is now busily employed in making plastic containers of all sizes. This firm specializes in thermoplastic containers of the smaller type for creams, toothpaste, toilet preparations and, with the new machinery on order, expect to develop their range. Presently it will be possible to make moulded plastic goods, such as cigarette cases and safety razors. This company is a self-contained unit, making its own dies and completing the finished articles in all the different details of production. Several experimental plastic products have been made recently, but the company feels that it cannot claim too many great developments in the near future, as really large production will only be possible when the new plant is installed.

Marbo Products is the name of another plastics factory making such items as fancy goods. Another Johannesburg firm is producing plastic powders in addition to finished plastic products such as beer bottle stoppers, honey jar caps, cosmetic jars and caps.

Other developments in the South African plastics industry are anticipated in the near future, as there is no doubt that plastics can be used by commerce and industry to provide many of those substitute materials needed to replace substances no longer available or severely controlled. So far the South African plastics industry is working on a rather small scale, and any new factories opened in the future are also likely to be of limited style. At the same time, it is envisaged that in the future some effort may be made to develop a really large plastics industry in the country and to undertake the manufacture of a range of domestic and industrial articles for sale in South Africa and for export to neighbouring countries. Before such hopes can be realized it will probably be necessary for the local industry to produce at a much cheaper selling level than at present. Plastics of local manufacture are expensive compared with the product previously imported, so that it has been largely due to the war that the manufacture of plastics in the Union has managed to progress in the last three years. Efforts will be made to reduce costs.

ENGINEERING BULLETIN.—The April, 1943, issue of "Production and Engineering Bulletin," published by the Ministries of Labour and of Production, contained much interesting information regarding efficiency in factories. Among the principal features are: Power Trucks for Efficient Internal Transport; On Night Work (some useful hints to those first changing over to night shifts); Volunteer Labour Service (a record of achievement of week-end volunteer workers); High Precision Work by Women, etc.

PLASTICS ADVERTISING.—Birkby's, Ltd., Liversedge, Yorks, manufacturers of Elo resins, have commenced national advertising, using the leading provincial papers for their campaign.

SOCIETY MEETING.—On May 11 the members of the Institute of the Plastics Industry are invited to attend a joint meeting with the Plastics Group of the Society of Chemical Industry at 7.30 p.m. at the "Windsor Castle," Victoria Station, London, S.W.1. The meeting will be in the form of a symposium on "The Practical Use of Plastics in Building and Structural Work." Mr. F. S. Snow, M.Inst.C.E., M.I.Struct.E., will open the meeting on behalf of the Institution of Structural Engineers and will be followed by Dr. A. Caress on behalf of the Institute of the Plastics Industry.

INSTITUTE OF THE PLASTICS INDUSTRY.—The annual general meeting of the London Section will be held at the Waldorf Hotel, Aldwych, London, on Wednesday, May 12, at 12.15 p.m. This meeting will be followed by a luncheon, after which an address will be delivered by Major T. Knowles.

Classification of Plastics

In Mr. Stevens' "Classification of Plastics," in our April issue, the well-known trade name of "Elo," the synthetic resins made by Birkby's, Ltd., was inadvertently omitted. Also "Kallodent" (I.C.I. polyacrylate) was rendered "Callodent." We regret both errors. British Resin Products, Ltd., remind us that the trade mark "Epok" covers also their coumarone indene resins and their modified rosins.

Resinoids and Other Plastics as Film Formers

By B. J. BRAJNIKOFF,
Consulting Electrical Engineer

XVIII.—Peculiarities of Physical Properties of High Polymers

THE analytical considerations outlined in the previous sections enable us to obtain a deeper insight into the relationship between the processes underlying the evolution of the molecular complexes and the characteristic features of their physical behaviour, in so far as they affect the plastics field generally and the film formation in particular.

The fundamental property distinguishing high polymeric products from other materials is the exceptionally large size of their molecules and associated with it the possibility of molecular deformation. For the linear, non-branching molecules (to the discussion of which we shall confine our attention in the current section, designating them as chains), a suitable measure of the molecular deformation is the change of entropy of the filamentary molecule, owing to its transition from the "rectilinear" shape into a more probable bent configuration. The basic aspects and possibility of the deformation, as well as the dependence of the deformation upon the length of the molecular chain, have been demonstrated in the works of Mark and Kuhn.[256]

While Mark and Kuhn have built up their deformation theory on the assumption of a free rotation of similar chemical groups in the chain (or links) with respect to one another with preservation of the valence bond, Bresler and Frenkel[257] have introduced the limitation of the freedom of rotation, by taking into account the presence of a potential barrier during the rotatory motion, conditioned by the interaction of the molecular links.

It should be remarked that the above-mentioned studies have been restricted, mainly, to the behaviour of an isolated chain. The limitation as introduced by Frenkel and Bresler is doubtless correct, and it is easy to see that, with the alteration of the size of the barrier within any assigned limits, the shape of the chain will continually change.

Moreover, no matter how thorough may be the analysis of an isolated chain, it is impossible to arrive through such to any quantitative conclusions regarding the behaviour of high polymeric molecules in condensed state, a circumstance of cardinal importance to the coating industry. In consequence of interaction of the links of the polymer, both among themselves and with the molecules of solvent, the magnitude of the potential barrier may vary equally well in the direction of increase and decrease. The latter aspect is due to the fact that both the forces of attraction and repulsion are essential to the potential barrier.

Direction of Processes from Thermodynamical Viewpoint

At this juncture it will be very helpful to make a brief excursion into the domain of thermodynamics, as it has an immediate bearing upon the discussion that follows.

In accordance with the present-day knowledge of the structure of matter, the heat energy of material bodies is to be regarded as a form of kinetic energy, i.e., the energy of random motion of the molecules. The most striking ocular confirmation of the kinetic theory of heat and the validity of the law of energy distribution in a system at thermodynamical equilibrium is furnished by the Brownian molecular motion. In Brownian movements, which can be demonstrated best

with the ultramicroscope, the molecules of the fluid medium in the immediate vicinity of a suspended particle collide in consequence of their oscillations, due to thermal agitation and sharing of it with their energy.

The equivalence of heat and work is known as the first principle of energy or the first law of thermodynamics, and is an extension of the principle of the conservation of energy, applied to thermal processes.

Almost all chemical processes are accompanied by change of temperature. The quantity of heat set free (as, for example, in the reactions termed by Berthelot "exothermic") in the course of a given chemical process is proportional to the mass of the substance taking part in it. The quantity of heat used up or developed in the combination of the chemical nature is designated as the heat of combination. When none, or only a part, of the heat supplied to the system is used up for the performance of external work, the internal energy must increase. The internal energy is very complicated in the case of solids and liquids, for the reason that, in addition to the complex structure of the molecules, as contrasted to gas, there are also combinations of the molecules with one another to be taken into account (forces of cohesion). Unless some special constraint is applied, changes of the temperature of a body are, in general, accompanied by alterations of length or volume.

In this connection, the direction of processes is of prime importance. In a closed system all processes take place in such a direction as not to bring the system into a less probable condition, a postulate which constitutes the essence of the second law of thermodynamics, as announced by Boltzmann in 1866.

Experience shows that the combination of the two laws of thermodynamics can also be extended to systems, in which other kinds of external work (as distinct from gas) are performed, such as chemical changes, solution, elastic deformations, and the like.

The processes, in which the probability remains the same, are reversible; they can pass through all their phases in the reverse direction. On the other hand, processes invoking an increase in the probability of the condition of the system are irreversible.

The most probable state for an isolated system is that of complete disorder, in which there are no directed conditions, such as differences of temperature, pressure, concentration. In this state there is no excess of energy in any one part of the system; the energy distribution is perfectly uniform, and the whole system is, therefore, at a uniform temperature.

According to Boltzmann, processes at variance with the second law are not impossible, but only in the highest degree improbable. The reason for this is to be found in the complex structure of the matter involved, which consists of an immense number of atoms and molecules. In the investigation of physical processes, account must be taken of the motions of these ultimate particles and the distribution of velocities among them.

The explanation of all phenomena on the basis of these elementary motions is the problem of the so-called statistical mechanics. From the above it follows that the probability of any given state of distribution increases as the number of particles involved is lessened. Hence, if the number of particles taking part in the process or the space it occupies is sufficiently small, the probability of the occurrence of the process may become so great that it can actually be observed once within a measurable time.

The investigation of Brownian molecular movement has led to the recognition that suspended particles of a size just visible in a microscope possess kinetic energy which they have derived from the thermal energy of their surroundings at uniform temperature. The visible motions of the particles are the result of particularly energetic impacts. Thus heat energy has passed over into actual bodies —as distinct from the molecules—in a greater degree than that corresponding to the thermodynamical equilibrium. Regions of the order of magnitude of the

particles displaying Brownian movement represent the limit down to which the concepts of temperature, pressure, concentration in their usual form still hold, and down to which we can still speak of the general practical validity of the second law of thermodynamics.

The notion of entropy, in terms of the thermodynamical considerations, is defined as a quantity, the product of which by the lowest temperature value of the process represents the number of calories not convertible under specified conditions into work but withdrawn in the form of heat. In other words, the entropy is a number, whose product by the temperature of the process gives the amount of heat involved in the process.

The concept of entropy, which is rather difficult to grasp from the purely thermodynamical standpoint, becomes easier to understand in the light of the theory of probability, namely, that the entropy of a state is a definite multiple of the natural logarithm of its probability.

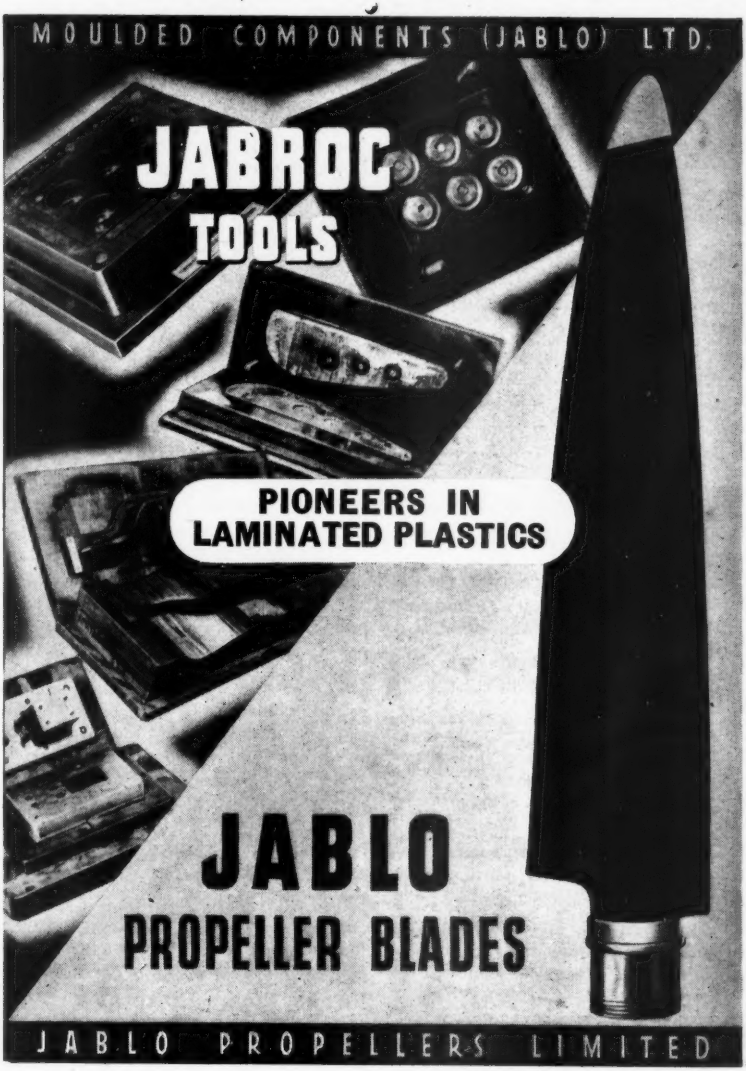
Hence, the quantities, which are descriptive of the state of a given system (e.g., colloidal solution, etc.), in that they have a definite numerical magnitude for every state of the system. These quantities are: the internal energy U, pressure p, volume v, temperature T, concentration of dissolved molecules N, and, finally, the entropy S. They are not independent of one another, but are connected by a certain functional relationship determined by the nature of the system. A change of one of these parameters of state causes, in general, a change of the others, although one or more of them may remain constant. Thus the state of the system can be varied while one of the parameters is kept constant: e.g., isopiestic processes (p = constant), isochoric processes (v = constant), isothermal processes (T = constant), isentropic processes (S = constant), processes at constant concentration, and so on.

Determination of the Molecular Configuration

At the present time there are no methods for the quantitative estimations of interactions between the links, which would enable the investigator to determine the shape of the chain molecule in a condensed system. Moreover, the most important properties of high polymers are evaluated precisely by the interaction of constituent links and the state of the chain. The anomalous elastic properties of a polymer[256] are consequential to the deformability of chains and are, therefore, determined by the state of the chains in the initial material. The term elasticity is meant here to designate the ability of a polymer to deform reversibly under the action of forces operating for a short interval of time. By the term viscosity is meant the value of internal friction of a body in the Newtonian sense under stationary conditions of the laminal flow.[258] The exceptionally large values of the viscosity of high polymers are the consequence of a great magnitude of the energy of interaction between the chains, which, in turn, is composed by the interaction of the links.

It should be noted that the processes of the regrouping of links, which determine the speed of bringing them to the stationary régime, progress with different velocities.[258] In the event of the regrouping of links, the period of relaxation depends on the energy of interaction between the links, whereas the relaxation period in the case of the regrouping of chains depends on the sum total of energies of the interaction of links in the chain. Therefore, the development of elastic processes proceeds at a far greater speed than the processes of viscous flow. Inasmuch as both processes, as indicated above, depend ultimately on the arrangement and the energy of interaction between the links, it is evident that in order to unravel the mechanism of these processes in greater detail it is necessary to introduce more definite concepts relating to the structure of high polymers.

Every deformation of a high polymer impels the chains to straighten and orient themselves in the direction of the deformation. By increasing the degree and the duration of the deformation, we can approach as closely as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we wish to the structure, which in a certain sense follows a regular pattern. Indeed, by means of suitable deformation, it is possible to attain the decrease of interlacing of the molecules in the course of their "straightening." In such a case, there naturally takes place, in the limit, a regular distribution of the links in the chains, as well as of the chains themselves. The appearance of a similar regular recurrence of the links and the chains makes it essential to examine in more detail the question of the phase transitions in bodies of this kind.

The State of Crystallinity

It is known that on stretching of natural rubber, there occurs a process of the alteration in the structure of the material, which is usually referred to as the process of crystallization. Moreover, for the substances with very large molecules, the notion of a crystal, in the ordinary sense of the term, often leads to misunderstandings. To describe a crystal of a low molecular substance, it is sufficient to indicate the position of the centres of gravity of the molecules and the space distribution of their elements of symmetry. This description is adequate so long as the molecules are small, and the vibratory motion of the separate parts of the molecule cause no change in its shape. But where the molecules are of gigantic dimensions and have the shape of flexible threads, the periodic distribution of the centres of gravity of such large molecules in space does not determine the periodic distribution of separate similar chemical groups of the chain.

It is not clear whether in that case a body should be regarded as high polymeric, when there is a periodic distribution of the centres of gravity of the chain molecules (i.e., when the criterion of the crystallinity is being fulfilled for bodies composed of small molecules), or when there is a periodic distribution of the centres of gravity of the links of the chain. If we use the criterion as has been suggested by Landau,[259] it is easy to reveal that a periodic distribution of the centres of gravity of chains, which undergo ceaseless deformation (due to thermal motion), corresponds not to a periodic, but to a constant function of density, holding true for the entire space.

On the other hand, the periodic variation of the density function conforms to periodic distribution of the centres of gravity of links. Hence, we are enabled to infer that the crystals of a high polymer may only thus be properly so called, when all links of all chains are arranged periodically. From the above it follows that in a crystal of a high polymer the chains should possess the "rectilinear" shape.

In the event, when the filamentary molecules are situated with some regularity relative to one another (for example, in the sense of the dependence of the directions of symmetry axes of separate chains), but are lacking the "rectilinear" shape, we obviously have the case of a liquid-crystalline phase.

Qualitatively, we are in a position to analyse the connection between the fusion temperature of a crystal and the degree of polymerization.

As is known, the equilibrium state of a system, at constant temperature and pressure, corresponds to the minimum of thermodynamic potential, or neglecting the variation of volume, which is insignificant in the case under consideration, to the minimum of free energy.

Let us consider the change of free energy for crystals of a homologous series, for instance, paraffins. Inasmuch as various homologues differ from one another only by the number of the identical chemical groups contained in the chain molecule, the internal energy (all thermodynamic quantities refer to the molar value of a substance) will grow in direct proportion to the number of links comprised by the chain (i.e., the degree of polymerization).

The free energy will also increase linearly with the growth of the number of chains, so long as the values of the entropy term in the free energy varies slightly. Indeed, at low degrees of the polymerization (i.e., for the lower homologues) the flexibility of the filamentary

molecule is negligible, and the molecule, with a great degree of the approximation, retains its "rectilinear" shape during the fusion of crystal. The analytical considerations, as outlined above, are, in essence, analogous to the well-known Trouton's rule, according to which the change of entropy in the evaporation does not depend on the molecular weight.

Thus, the well-known fact of the elevation[256] of the fusion temperature with the growth of the molecular weight of a homologue will be observed as long as the postulate of constancy of change of entropy during the fusion holds true, i.e., so long until the chain in the crystal and in the liquid may be regarded as preserving its configuration. In other words, this position will obtain as long as we can disregard the change of entropy, conditioned by the flexibility of chain (which is always possible with sufficiently short chains), that is, for so long, while it is permissible to restrict the estimation of the entropy variation, conditioned by the mutual arrangement of the molecules, without reckoning the alteration of their own configuration.

Indeed, in the process of fusion we have

$$T = \frac{U_{crystal} - U_{liquid}}{S_{crystal} - S_{liquid}},$$

where the symbols denote the same parameters as before, i.e., U is the internal energy, S is the entropy, and T the temperature on the absolute scale.

For all lower homologues the value of the denomination is constant, whilst the numerator grows with the increase of the degree of polymerization. Whence it follows that the temperature of fusion also should rise.

However, for high polymers the flexibility of the chain becomes so considerable that the change of entropy, in consequence of deformation of the chains, may greatly exceed the usual variation of entropy. For instance, Meyer and other workers[260] recently showed that the change of entropy in the process of solution of high polymers (viz., rubber, cellulose, etc.), may exceed ten, hundred and even thousand times the value of entropy of mixing liquids.

Therefore, in the other limiting case, with very high degrees of polymerization (i.e., when the flexibility of the filamentary molecule becomes insignificant on account of its exceptionally great length), the change of entropy during the fusion will be determined, in the main, only by that its part, which is conditioned by the alteration of the configuration of the chains in their transition from one state to another.

Hence it is evident that, with the sufficiently large dimensions of chains, the entropy part of the change of free energy will be precisely determined solely by it, and not by the value of internal energy. Thus, in this limiting case the temperature of the fusion should diminish with the growth of the degree of polymerization.

In the light of the considerations as outlined above, it is legitimate to come to the conclusion that the performance curve giving the dependence of the fusion temperature of the crystals of the homologous series on the degree of the polymerization must have a maximum.

The latter circumstance permits us to expect that a series of high polymeric substances should, at normal temperature, already possess either a liquid or liquid-crystalline structure. Indeed, it is a well-known fact that a number of investigators[261] have observed the absence of crystalline structure in many high molecular compounds (viz., rubber, etc.).

It has often been suggested that the cause of the absence of the crystalline state is a slow rate of kinetics in attaining a regular arrangement by the long chains owing to their magnitude and interlacing. Consequently, the fluid structures of high polymers are regarded as unbalanced systems (glass-like state).

In the opinion of Karguin and Slonimsky,[262] who have done a good deal of research on high polymers at the Moscow Institute of Physical Chemistry, the liquid structure of high polymers may be balanced even at very low tempera-

tures. As to the problem concerning the absolute value of the fusion temperatures, it can, of course, be decided only by experimental observations for each type of high polymeric substance separately. None the less, it is possible to affirm that, with the raising of the degree of polymerization, the temperature of fusion, after passing through the maximum, begins to diminish and may reach very low values (at sufficiently high degrees of polymerization).

Of course, any intermediate hypotheses, allowing for the existence of regular crystals surrounded by an amorphous substance, are reducible to the admission of the unbalanced state of the material and become absurd in passing to solutions. The formation of a crystal is connected with the phase transition, and the consideration of "swarms" (the presence of which is inevitable in any liquid, including a high polymeric one), as a new phase, automatically leads to the recognition of the continuity of the phase transition, which contradicts the accepted concept of a crystal.[259]

Anisotropy

Let us now pass to the discussion of a possible state of high polymers—the liquid-crystalline condition. According to Landau,[259] the sphere of existence of the liquid-crystalline state is particularly great in the case of high polymeric compounds.

As has already been pointed out, the liquid-crystalline condition is characterized by the presence of anisotropy (i.e., by the non-equivalence of various arrangements of neighbouring molecules in the assigned situation of a given molecule) at the constant value of the above-mentioned function of density. Here we have the "non-rectilinear" chains, distributed in some regular fashion. Indeed, in the case of the chain molecules of very great magnitude, even after the transition to a "non-rectilinear" shape, they still retain an asymmetry (i.e., the volume occupied by the bent molecule is not a spheroid). Naturally, the interactions between such gigantic molecules will be sufficiently great even at a very feeble interaction between separate links. As a consequence of this interaction, there may occur the orientation of such large bent molecules along a certain general direction, in the total absence of the regular arrangement of individual links (the absence of an ordered distribution of links conforms to the constancy value of the density function). Therefore, it is possible to expect for high polymers the existence of a liquid-crystalline state within a large range of temperatures.

In considering anisotropic properties of high polymers it is necessary to take into account not only the molecular interactions but also the influence of the external forces. Usually, the high polymeric materials are being found and studied in already oriented condition, i.e., in the anisotropic state, caused by previous mechanical deformation or by the imposition of some other extraneous field of force.

Karguin and Slonimsky[263] emphasize that the manifestation of anisotropy considered in itself alone, regardless of the field of force acting on the body,[256] is not directly connected with the phase transition from the fluid to a liquid-crystalline or crystalline state. The same circumstance holds true in the case of a high polymeric body, which has in the past been subjected to the action of the field of force, if the period of relaxation is appreciable.

The appearance of anisotropy or the alteration of symmetry generally is a sign of the phase transition in the event of the complete absence of the external field. It is obvious that in the presence of the field of force, the asymmetric molecules, which are in the state of equilibrium, will tend to arrange themselves according to the lines of force of the field. Thus, it is possible to change continually the anisotropy of the system, where the developing symmetry will coincide with the symmetry of the applied field. This continuous modification of the

anisotropy of a body under the action of a constantly varying field of force, or the change of symmetry of the body with the alteration of the field symmetry, cannot be regarded as a phase transition.

Indeed, with respect to the external field, the body remains anisotropic. It must be kept in mind that in the field of force, generally speaking, not all directions are equivalent. If the same non-equivalence is possessed by the substance under consideration, it is natural to regard such a body as isotropic in relation to the field.[257] It should be noted that an isotropic body thus defined will appear anisotropic under the investigation of other physical properties of the substance associated with its structure, but not connected with the impressed field. The unmistaken indicator of the phase transition in the external field of force will be the development of symmetry not coinciding with the symmetry of field, i.e., the appearance of anisotropy in respect to the external field.

All the above considerations refer, of course, to the balanced state of the material in the external field of force. In analysing the unbalanced states of a substance, it may occur that symmetry of the body will differ from the field symmetry, which condition will always be accentuated in materials having lengthy periods of relaxation. In this event, even the appearance of difference between the field symmetry and that of the body will not uniquely testify to the presence of phase transition.

A specially important case attaches to the unbalanced state of bodies with long periods of relaxation following the removal of the field; a case in point is, for example, a specimen of a high polymeric material, subjected to a prolonged deformation, immediately after its release from the influence of the deforming forces.

In this event the body may for a lengthy interval possess a very high anisotropy while free from the action of extraneous forces. Thus, the presence of anisotropy in a substance (e.g., giving double refraction of light rays), in the absence of certainty that the body is in the balanced condition, does not permit us to draw any deductions with regard to its phase state.

It is worthy of note that the change of the interference pattern obtained by the Röntgenographic method, while the substance is under the action of external forces, also does not prove the presence of phase transition, and may be conditioned by field symmetry.

Consequently, even such information, as the alteration of the X-ray dispersion diagram, cannot always yield the unique data on the phase transition in high polymers.

Examination of Thin Films by the Electron Diffraction Method

The question as to whether a high polymeric material is a crystalline or amorphous body at normal temperature is extremely important in the explanation of physico-chemical properties of a given high molecular compound. If we assign to high polymeric products an amorphous structure, then we will have to interpret in an entirely different way the behaviour of these substances when they undergo mechanical deformation, their reaction ability, swelling, solubility, etc.

In these cases, the balanced condition of the body is reflected in the isotropic state, the mechanical deformations are accompanied merely by the reversible structural modifications and are of the relaxation character, the solution is described as the mixing of the liquids. Here, naturally, the concept of inter- and intrami-cellar reactions loses its meaning. In the light of the existing notions on the amorphous nature of high polymers, the approach to the question that arises in the interpretation of X-ray diagrams should be made from a totally different angle. In the event, when a high polymeric substance possesses no crystalline structure, the determination of the parameters of the space lattice or the distances between the lattice planes loses all meaning. In the Röntgenograms we obtain a series of interference patterns formed as a result of

any periodicities in the structure. In this case it is impossible to speak strictly of the identity periods. The arrangement of the atoms in the amorphous body can be described with the aid of the distribution curve of the density in relation to the distance calculated from any atom, arbitrarily chosen as the origin of coordinates. On this curve there exist the points of maxima, which correspond to the distances most frequently met with between the atoms. Those identity periods, which are determined from interference patterns of an amorphous body, may be referred to the loci of these maxima on the distribution curve. The interference pattern also depends upon the wavelength of the dispersed radiation. With the small wave-lengths, there come into play the deviations from the most probable identity periods, and, thus, interferences corresponding to the most pronounced maxima on the curve of distribution of the atoms in terms of distances between them, will tend to vanish with the diminution of the wave-length of the dispersed radiation.

In the interference patterns derived from high polymeric materials we deal with the two types of interferences: (1) the interferences conditioned by a regular arrangement of the atoms in the molecule (intramolecular dispersion), and (2) those evoked by interactions between the molecules (intermolecular dispersion).

The interatomic distances in the molecule are kept relatively exact (the deviations are caused only by the vibratory oscillations of atoms in the molecule), and, therefore, the intramolecular dispersion, practically, does not depend on the wave-length. Thus, interferences corresponding to intramolecular dispersion should be present in the interference patterns. As the wave-length of the dispersed radiation increases, there should emerge new interferences, corresponding to intermolecular dispersion. For this reason it is impossible to obtain an exact understanding of the structure of an amorphous substance from the electron diffraction pattern produced by the use of one wave-length. By utilizing sufficiently small wave-lengths, to obtain only the intramolecular dispersion, it becomes feasible to arrive at certain inferences as to molecular structure.

Deductions

In conclusion, it should be pointed out that the peculiar charactertistic of high polymers is the substantial dependence of physical properties not only on the chemical constitution and the magnitude of the molecule, but also on its configuration. Indeed, should there be a body with very large rigid molecules, which do not vary in their shape in the cause of phase transitions, then its physical properties in the equilibrium state would be described by the same laws as those in the case of substances with small molecules. In the latter instance, the whole molecule is an independent structural unit, irrespective of its size. For high polymeric flexible molecules, the molecule itself cannot be regarded as a structural unit possessing non-varying properties. Such a molecule represents a complex system whose structural units are the individual links.

This circumstance gives rise to the "duality" of the physical properties characteristic to high polymers, conforming to the two products of the structural units (chains and links). In other words, apart from the usual consideration of the totality of molecules, in the case of high polymers we should simultaneously take into account the fact that the molecule itself is the totality of links.

In both the totalities there may occur, independently, orientation and disorientation of the structural elements with corresponding periods of relaxation. Therefore, in respect of high polymers we should distinguish the two groups of relaxation periods, relating to the distribution of links in the chain, and the arrangement of chains relative to one another. Both groups of processes exert an influence upon the physical properties of high polymeric materials. Depending on the type of the groups which are dominant in the process, we obtain by suitable estimation one or another characteristic

feature of the examined physical property of a high polymeric substance. Thus, for example, in studying mechanical properties, with very rapid deformations, we modify in the investigational process merely the shape of the chains, but not their mutual arrangement.[264] Here the processes are connected with the displacement of chains as a whole (i.e., the processes of viscous flow), where the relaxation period is very great in comparison with the time of deformation. The behaviour of the materials in this case will be that of a purely elastic nature.

On the contrary, with very slow deformation in the substance, only viscous properties will be developed, with almost complete lack of elasticity. The latter explanation holds perfectly true in the case of absence between molecules of the supplementary bonds of the type peculiar to vulcanization.

Similarly, in the examination of the structure of material, dependent on the method of the physical analysis employed, we obtain one or another kind of results. In studying the double refraction (large wave-lengths), we take into account merely anisotropy, conditioned by the distribution of chains.[264]

In examining the diffraction of high velocity electrons (small wave-lengths), we derive a notion concerning the behaviour of separate links, but obtain no information on the arrangement of chains. Therefore, one and the same substances may, under dissimilar methods of investigation, give different results. For instance, in the studying of double refraction, a material may appear anisotropic, whereas with the help of the electronographic method, the same substance will yield a pattern characteristic to an isotropic body (the absence of structure). It should be remarked that for the systems with the rigid arrangement of molecules the results by both methods will coincide.

From the foregoing discussion it is evident that, by applying other physical methods of the examination of high polymers, we shall obtain variable results, dependent on the fact, which of the two groups of processes taking place in the substance is more essential for a given method of determination.

Obviously, it is quite possible to obtain all the intermediate cases as, for example, in studying not very rapid and not too slow deformations.

Unfortunately, this " duality " is not usually taken into consideration in the modern methods of the technical examination of high polymeric materials; the consequence being the divergence often observed in the industrial practice between the test data and the actual values yielded by the substance in exploitation. In order to account for the factor of " duality," it is necessary, first of all, to introduce the temporary characteristics.[265, 266]

(To be Continued).

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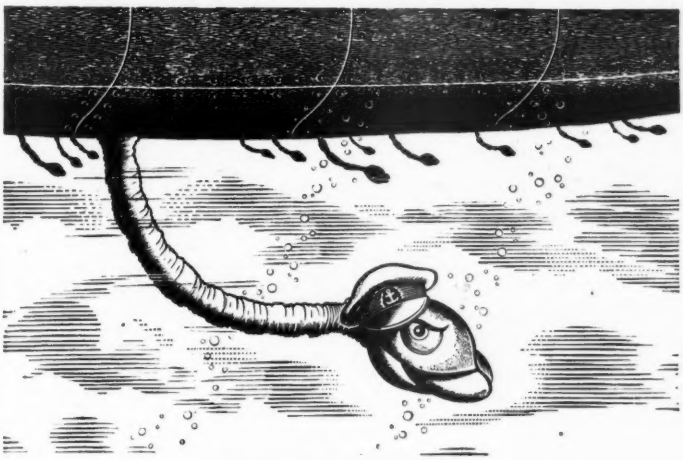

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